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*Strategies for Defining the
Army's Objective Vision of
Command and Control
for the 21st Century*

Edison M. Cesar

Arroyo Center

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Preface

This report provides the results of a concept-formulation project that examines the Army's needs to conduct command and control on the move (C²OTM) and some of the ways of satisfying those needs. As a concept formulation study, it intentionally lacks a rigorous examination of system complexities, of their capabilities and performance, and of their cost trade-offs. However, the study does identify informational and physical categories that can be used to evaluate C⁴ architectures qualitatively, and later quantitatively, and it provides suggestions for ways to make comparisons between them. Study results were briefed at TRADOC, Ft. Monroe, the Battle Command Battle Lab, Ft. Leavenworth, and at the Signal School and Center, Ft. Gordon.

The report serves to document a concept-formulation study effort begun in 1992 with tasking from TRADOC directed at the C²OTM vehicle operations and command post restructuring. Initial findings showed the importance of the operational C² system to any success for C²OTM vehicles on the battlefield and improvement of command post operations. From these findings and broader tasking from the Deputy Chief of Staff for Operations and Plans and the Deputy Chief of Staff for Intelligence, the emphasis on analysis of the operational C² systems begun in this paper was continued. Results of follow-on efforts have been described in related work in progress by Pat Allen and Ed Cesar on Army C⁴I architectures.

The research was conducted within the Force Development and Technology Program of RAND's Arroyo Center, a federally funded research and development center sponsored by the United States Army. The report will be of interest to those who are seeking better ways to help commanders perform their missions to ensure the Army can meet future challenges. Specifically, it will contribute to those responsible for implementing the Army Enterprise Vision, the Army Digitization Office, the Battle Command Battle Laboratory, and those associated with the development of Force XXI operations.

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Summary

Introduction

The uncertainty in the changing world situation and the diversity of crisis situations U.S. forces may face in the future reinforce the need for force commanders at all levels to be better able to command and control their forces, particularly at the operational and tactical levels. By being able to execute command and control (C²) rapidly, effectively, and continuously, forces may be able to quell disturbances in early stages and perhaps limit the need for larger forces or for longer operations.

With improved C² as a goal, this document presents the results of a concept-formulation study that took an initial look at the command and control on the move (C²OTM) situation as a whole, postulated a set of operational objectives derived from experiences in Operation Desert Storm (ODS) and from observations based on past RAND research in the area, and reviewed the Army's current and evolving C² subarchitecture¹ against these objectives. The document also suggests some elements that can help any C² subarchitecture better meet the postulated operational objectives.

Deriving Operational Objectives for C²OTM

ODS Lessons Learned

During Operation Desert Storm (ODS), battlefield information—which included intelligence and data on friendly force location and status, terrain and weather, battle damage assessment, and combat service support (CSS)—was delayed in getting to commanders. Command posts (CPs) were unwieldy. In addition, communications and automation facilities were slow to deploy to the region and were not always able to keep up with fast-moving tactical units. This was partly because Mobile Subscriber Equipment (MSE) was unable to keep pace with the maneuver units, and the range of the combat net radio was insufficient to support mobile operations in such a large region. Moreover, the flow of data

¹A distinction is made between the meta-architecture that includes all DoD system networks and the subordinate architectures referred to in this report, which are called C⁴ subarchitectures.

between sources and users was not streamlined or smooth, because ODS relied on a large variety of systems and diverse software controlled by various Department of Defense agencies that differed in communications media, operating procedures, standards, and protocols. Beyond this, sufficient awareness of the situation among all commands was also lacking. There was no common picture of the operation (CPO) at the same time either vertically or horizontally across command levels, and because the Global Positioning System (GPS) was not integrated into the operating systems, there was no accurate, timely, or uniform assessment of the friendly force status or locations of units.

These findings imply the following needs: (1) timely reports for C² during mobile operations; (2) smaller, more mobile CPs; (3) automated reporting of friendly asset location to help counter fratricide; and (4) range extension for the Combat Net Radio (CNR).

Observations from Other RAND Research

This study took advantage of experience and knowledge gained from a series of RAND studies, including studies of conflict scenarios and contingency operations, mobile operations, CP structure, communications, space-based systems, automation, image displays, sensors, quantifying and measuring system capabilities in operational outcome terms, and performing system trade-offs.

These studies suggested (1) that the connection architecture for the intelligence system lacked responsiveness; (2) that the MSE required a lot of time to deploy and could not keep pace with maneuver units when they were engaged in combat (a finding confirmed during ODS); (3) that commanders prefer imagery to written messages and desire that information be simultaneously broadcast to units participating in the same operation, rather than relayed serially through the chain of command; and (4) that the heavy reliance on space communications during Operation Urgent Fury and ODS, which included leased commercial terminals and transponders like the International Telecommunications Satellite (INTELSAT), offered many advantages (e.g., wide area coverage, the ability to exchange imagery, and increased ground mobility).

Future Operating Conditions

We assumed that, in the future, there will often be rapid deployment to regions where units will converge and meet for the first time and that combat and noncombat operations will sometimes take place concurrently in the same region. We further assumed that joint and combined elements will need to work closely

together to synchronize operations; that these operations will be complicated by differences in equipment, doctrine, software, standards, and procedures; that connectivity will have few interfaces between nodes; and that architectures will furnish continuous connectivity between deployed forces and the sustaining base in CONUS and possibly an active region.

Operational Objectives for C²

From the observations and assumed future operating conditions noted above, we postulated eight operational objectives for C² architectures:

- The ability to deploy forces rapidly to any region in the world, unencumbered by excessive equipment and its operators
- Intraregional C² mobility equal to or greater than that of the deployed forces
- Infrastructure for C² in place in the region ahead of the operational forces and operating as soon as it is needed
- Reports about the environment, enemy location, activities, and targets, and location and status of friendly forces available to commanders and their staffs at all times
- Reports about the situation to protect and sustain the force available at all times regardless of mission, including noncombat operations
- Position location at the small-unit and vehicle levels, automatically collected, analyzed, and disseminated to one or more central locations to help guard against fratricide
- The ability to assimilate forces in deployed commands rapidly and continuously and to disseminate, exchange, and display essential data during nonconflict periods while forces are assembling and preparing for operations
- Intelligent displays with decision support aids at command levels down to battalion.

Deriving Information and Physical Requirements for the Operational Objectives

Given these operational objectives, we identified a set of informational and physical needs that the components of any command, control, communications, and computers (C⁴) architecture must satisfy.

Informational Needs

The subarchitectures and their systems must, first, furnish the information needed to support commanders' current and planned operations (i.e., reports that are timely, accurate, relevant, and understandable). Second, the reports generated by the subarchitectures and their systems must be readily understood by joint forces, so they can be interoperable and comprehensible by all the participating Services, combined forces, and civilian agencies, when necessary. Third, the reports must be comprehensive, including all categories of reports needed to support operational planning and decisionmaking. Fourth, they must be responsive to commanders' tasking to meet their changing needs.

Physical Needs

The communications equipment and systems that comprise the subarchitectures must, first, be readily available to rapid deployment forces. Second, they must be self-sustaining (i.e., able to operate in a region that has little or no available infrastructure). Third, they must be as mobile as the forces they support, perhaps with ground terminals mounted in high-mobility multipurpose wheeled vehicles or in helicopters. Fourth, they must be adaptable to rapid and sudden changes in the environment and in the conflict situation, as well as to changes in the types and numbers of users, and the mission. Fifth, they must be reliable and robust (i.e., they must be sufficient for continuity of operations, balancing reliability of support and mobility reduction; must be self-restoring; and must help CPs survive by not emanating telltale signatures, and by incorporating communications security and anti-jamming capabilities. Sixth, they must both support and be supported across the CSS spectrum.

One final need, which is neither informational or physical (but which is critical) is that the architectures and their systems that provide these capabilities must be affordable.

Ranges of Quantifiable Measures for Informational and Physical Needs

Although we did not actually measure the above informational and physical needs, we did examine a range of measures for each one. For example, for the first informational need, "Supportive of operations," potential quantifiable measures include timeliness, accuracy, and adequacy of data to enable planning and decisionmaking. And the first physical need, "Available," has a time

dimension that ranges from having the C⁴ equipment in the region before early entry forces arrive to arriving with or after those forces.

Analysis of the Army's Current and Evolving C⁴ Subarchitecture

The Army's current C⁴ architecture is based on the C² Mini-Functional Area Analysis Study and the Military Satellite Communications (MILSATCOM) Architecture Study. It is based on the philosophy that reports from all, or as many as possible, of the numerous inter- and intraregional systems should go directly to the commanders and their staffs.

While the rationale for the current architecture is good, it does not do a very good job of meeting the informational and physical needs discussed above. Specifically, it contains an ever-increasing number of diverse systems, which makes it impractical to accommodate. As a result, it lacks interoperability within itself, with the other Services, and with U.S. allies and friends. Although it can supply data and reports from several different subarchitectures to commanders in the field, the data and reports must be first integrated before they can be used to determine relevance to current or planned operations. Not only are these data different at the standards, format, and protocol levels, which blocks physical interoperability, they are also structured differently to conform to data standards according to individual functional domains (stovepiping). Consequently, the Army's present C⁴ architecture is inefficient in terms of its configuration, equipment, and personnel, which can delay decisionmaking and risk unnecessary exposure to personnel.

The Army is evolving its current architecture by integrating it with the Army Tactical Command and Control System. In this architecture, the CPs and the command and control vehicles (C²Vs) receive data from a variety of collection, production, and dissemination facilities (CPDFs),² each devoted to a particular function (e.g., CSS, intelligence, and other situation awareness reports), as well as from a number of sensors. The data products are sent to users in the region primarily over terrestrial MSE links. The architecture would be augmented by satellite links, and although there are plans for some reports to be broadcast to users and some space-based systems may be used for that, the plans call for doing so only for specific kinds of data along certain functional domain lines (e.g., warnings), rather than for all kinds of data.

²The CPDF is a term we coined to describe a central place where all source collection, production, and dissemination operations are performed and standard and special types of reports are prepared and disseminated.

Notwithstanding these incremental improvements, this subarchitecture is unwieldy and difficult to control, primarily because various kinds of data and formats from different data sources all converge at different times and at a single place for the commander to integrate and try to make sense of. This means that a C²V for the commander and his staff would probably require a multitude of different receivers and antennas to receive reports from all the different CPDFs and sensors, and the large number of transceivers with associated radio frequency bands and antennas would adversely affect the CP's survivability and the C²Vs' mobility. In addition, this subarchitecture is still divided into physically dispersed processing centers set up according to, and optimized for, the functional domains (e.g., CSS, intelligence, fire support) and their unique sub-subarchitectures. Finally, deploying the large amounts of diversified equipment required at each CP would involve many operators and high costs.

Ideas for Optimizing C⁴ Architectures

Given the shortfalls in the Army's current and evolving C⁴ architecture, we examined some ideas for optimizing C⁴ architectures to help them meet the informational and physical needs.

Computer-to-Computer Communications

A major drawback to C² efficiency is that data transfers between computers currently take place over architectures that are not optimized for such transfers. In the past, except for Air Defense subarchitectures, all communications required the direct action of operators at both the sending and receiving ends. Now, many data exchanges are automated, taking place much faster than humans can assimilate or act upon.

Differentiating between the architectures for person-to-person communications and those for automated computer-to-computer (CtC) data exchanges may be a valuable concept. Such CtC exchanges, especially digital data transmission, are definitely on the rise and are expected to increase.³ Some current and evolving examples for military applications include the following:

³Subsequent to this study, the Army initiated a major effort to digitize the battlefield. This effort is being managed by the Army Digitization Office as part of the Force XXI activities. Three major exercises are included in the plan: a digitized Battalion Task Force XXI (94), a digitized Brigade Task Force XXI (97), and a digitized Division XXI (99). The digitization of the battlefield initiative is one of three thrusts the Army is pursuing to achieve Force XXI.

- On-board data processing
- Automated unmanned aerial vehicle operations
- Automated data relays and switches
- Integrated GPS receivers connected to control centers by line-of-sight satellite relays
- Automated logistics tracking and inventorying
- Teleoperated mines and unattended data-linked ground sensors.

In particular, CSS would benefit from automated collection of data on equipment status and consumption of petroleum, oil, and lubricants; munitions; and other consumables derived from on-board sensors connected to small, low-cost transponders installed in major items of equipment. The transponders would be activated either automatically or upon command to send stored data periodically about a system's status and performance via space-based links to the CPDF.

Switchboard in the Sky

Another idea for optimizing C⁴ architectures is to push intelligence and other reports from the sustaining base to an intermediate point that is either actually or virtually above the active region in which operations are being conducted. We referred to this point as a "switchboard in the sky" (SIS), which can be conceptualized as a sort of "data salad bar" that would allow users to select only those reports of interest to them and in the amount of detail relevant to their needs. Thus, the problem commanders often complain about, that of "information overload," can be avoided. Instead, a commander would be able to access what he wants to know about his particular area selectively—including his rear area—or the entire region of operations, as well as about hostile elements on his flanks, to the rear of his position, or deep in his opponent's rear area, without becoming overloaded with nonessential details about the entire region.

We also elaborated on the places where database and other memory storage would reside. The SIS concept envisages relaying reports containing graphical images with amplifying text and other formats to users in the region by collecting, updating, and storing the data on line until users request it. Each CPDF connected to the relay would serve as a central clearing house for data in both directions—to users in the format and resolution they require, and from users to the sustaining base through the SIS (e.g., CSS consumption by commodity or service type and by location).

Common Picture of the Operation

Another important idea to help optimize C⁴ architectures is the concept for a CPO. Actually, we mean a unique perception created in the mind of each recipient of data with the help of reports that become the basis for decisions. Although some aspects of a perception can be shared by more than one recipient of the same data or report, a single perception cannot truly be common. The CPO would be a common framework for data and standard report formats in which many aspects might be shared among recipients by means of a common data set. The reports from which the CPO is created would consist of details provided in response to the stated informational needs of individual commanders and would be designed to reduce the uncertainty about their own decision space.⁴ This process envisions using information agents to create and update commanders' CPOs and presenting most of the data to be exchanged between individuals in soft copy image formats, e.g., maps, overlays, and annotations (icons, lines, arrows, numbers, and limited text).

If the same data standards and profiles are employed by all the Services, the use of such common graphics would greatly enhance interoperability for joint operations, since graphical displays can transcend organizational and linguistic barriers. In addition, the objects depicted in the CPO might also portray safe routes for medical evacuation or supply movements for noncombat operations, such as disaster relief, or the location of mines and the capability of hostile forces for conducting combat operations.

An important part of actualizing the CPO concept is determining commanders' information needs. This could be accomplished by automatically recording the computer operations commanders at various command levels perform for a particular scenario and mission. This information might also be recorded according to the type of unit, since the sequence, types of data, and amount of detail the commanders request to plan or execute their missions will reflect their general information preferences for decisionmaking.

Analysts could then perform sensitivity analyses to determine generally what kinds of reports are needed for various kinds of decisions (e.g., for planning, attacking, and defending), as well as what types of reports the CPDFs should prepare and how often to disseminate them. The results of these kinds of analyses could serve as tools in answering engineering-design questions about an

⁴*Decision space* refers to all subject matter that is related to a set of decisions for which a decisionmaker is partially or totally responsible and to the set of all possible decisions the decisionmaker may make.

architecture's design for data acquisition and information display and its supporting systems and databases.

Conclusions and Recommendations

The main conclusion of this concept-formulation study is that it is feasible for joint task force elements to operate while moving by adopting new techniques to assess information requirements and new technologies, architectures, systems, and procedures, particularly space-based systems. This requires major revisions to the current architectures that connect data sources with data users in a region of operations.

Given this conclusion, we recommend that the Army

- design, in conjunction with the other Services and DoD agencies, from the top down, a completely new open architecture (both hardware and software) intended primarily for C²
- use a common data structure for all the Army's functional domains (e.g., intelligence, maneuver, CSS, fire support, aviation, air defense)
- analyze, once the new architecture's design is complete, the potential utility of all equipment and software currently in use and on order to determine its suitability, using the Louisiana Maneuvers demonstration program and the Army's campaign plan for Force XXI as a test bed for such evaluation
- discard unsuitable equipment as soon as possible (to reduce legacy problems) by stopping any ongoing production and replacing each with items compatible with a new architecture
- look for potential resources from industry and elsewhere outside the Army by conceptualizing and describing new applications for C²-related technologies that have both civilian and military uses.

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Abbreviations

ACTS	Advanced Communications Technology Satellite
ADO	Army Digitization Office
AOR	Area of responsibility
APC	Armored personnel carrier
ASARS	Advanced synthetic aperture radar systems
ASAS	All Source Analysis System
BDA	Battle damage assessment
BCV	Battle command vehicle
BOS	Battlefield operating system
C ²	Command and control
C ² OTM	Command and control on the move
C ² V	Command and control vehicle
C ³	Command, control and communications
C ⁴ I	Command, control, communications, computers, and intelligence
CtC	Computer-to-computer
CDS	Common data set
CGDS	Common graphical data set
CGS	Common ground station
CNR	Combat net radio
CONUS	Continental United States
CP	Command post
CPDF	Collection, production, and dissemination facility
CPO	Common picture of the operation
CS	Combat support
CSS	Combat service support
EPLRS	Enhanced Position Location Reporting System
GATS	GPS Army Tactical Command and Control System Tracking System
GPS	Global Positioning System
JSTARS	Joint Surveillance and Target Attack Radar System
LEO	Low earth orbit
LOS	Line of sight
METT-T	Mission, enemy, troops available, terrain-time
MCS	Mission control system
MEO	Medium earth orbit

MI	Military intelligence
MILSATCOM	Military satellite communications
MSE	Mobile subscriber equipment
MSRT	Mobile subscriber radiotelephone
NTC	National Training Center
ODS	Operation Desert Storm
PtC	Person-to-computer
POL	Petroleum, oil, and lubricants
PtP	Person-to-person
SIS	Switchboard in the sky
TACSAT	Tactical satellite
TENCAP	Tactical Exploitation of National Capabilities
TOC	Tactical operations center
TPFDDL	Time Planned Force Development and Deployment List
TRAP	TRE (tactical receive equipment) related applications
TRITAC	Tri-Service Tactical Communications System
UAV	Unmanned aerial vehicle

1. Introduction

Background

With the collapse of the Soviet Union, the defense guidance and planning focus of the United States has shifted from a single global scenario requiring planning for only a few geographical areas to an array of operationally and geographically diverse conflict scenarios, both combat and noncombat. This focus reinforces the need for commanders at all levels to be better able to command and control their forces, particularly at the operational and tactical levels. With the current increased emphasis on joint and combined operations, all the forces must be jointly interoperable (even, at times, with allied forces), and commanders must have the information they need while en route to the conflict area, as well as immediately on arrival there—what we call command and control on the move (C²OTM).¹ By being able to execute command and control (C²) rapidly, effectively, and continuously, a small force may be able to quell a disturbance in its earliest stage and perhaps limit the need for a larger force or for a longer operation.

C²OTM considerations often center on a vehicle and its information-reception capabilities. Information content received is also vital, of course, but the information requirements of decisionmakers have not always been a central focus. Currently, Services either own or have access to a variety of valuable databases and highly capable collection systems. Connecting commanders to the data they want is proceeding gradually through many efforts, but effectiveness is limited by inadequate interoperability within and across Services and Army commands, beginning at the fundamental level of data elements and standards.

Objective

This document reports the results of a concept-formulation study that took an initial look at the C²OTM situation as a whole. More specifically, the study

¹The terms C²OTM and *mobile communications* refer to having sufficient mobility to support operations in regions effectively and efficiently and do not necessarily mean provision of operational (battle command) communications to units at all command levels while they are moving continuously. C²OTM is primarily needed by brigades and battalions when they are deployed and by corps through division when they are en route to a region.

addressed what a C²OTM system would need to be able to do, based on criteria derived from recent experience in Operation Desert Storm (ODS) and what we have observed about C² in past RAND projects. We then use these criteria—both informational and physical—to evaluate the Army's current and planned C² architecture. After that, we offer some suggestions about C² elements that could be used to better meet the criteria, then provide some general conclusions and recommendations.

Throughout this document, we use the word *information* in the context of situational knowledge that is relevant to a particular decision or group of related decisions needed to support a plan or to execute operations. This includes warning to protect friendly forces in a given area, place, and time. The information content supplied by any architecture cannot be the same for all recipients, because each user has different decisions to address.

Organization of This Document

Section 2 describes what we learned about C² in ODS and sums up knowledge gained from other RAND research. Section 3 postulates operational objectives for command, control, communications, and computers (C⁴) and, based on these, identifies physical and informational needs that architectures for C⁴ must meet. Section 4 describes the Army's current C⁴ architecture and compares the architectures qualitatively against the needs identified in Section 3. Sections 5, 6, and 7 examine some elements that can help meet the criteria defined earlier—specifically, the concept of a “switchboard in the sky” (SIS), the role of computer-to-computer (CtC) data exchanges in optimizing their architectures, and the concept of a common picture of the operation (CPO) and of how it can be used to accurately determine commanders' information needs and preferences. Finally, Section 8 provides some conclusions and recommendations.

Appendix A describes a concept for acquiring new information technologies in discrete steps, and Appendix B describes a concept for employing space-based proxy platforms at the National Training Center.

2. Deriving Operational Objectives for C²OTM

To take an initial look at the C²OTM situation as a whole, we began by deriving some operational objectives for C² based on what ODS revealed, what past RAND research showed, and what our assumptions about the future environment portend.

What ODS Revealed About C²

One of the lessons of ODS was that the performance of the tactical-level C² component of the current architecture for tactical C⁴ was inadequate to support mobile combat operations (House Armed Services Committee, 1992). This occurred primarily because the current system was optimized to support a European or Korean scenario that envisioned limited force mobility and operations in depth. Below, we first summarize those difficulties, then discuss the needs they imply.

Summary of ODS C² Difficulties

During ODS, essential battlefield data—including intelligence, tactical ballistic missile warning, friendly force location and status, terrain and weather, battle damage assessment, and combat service support (CSS) data—were delayed in getting to commanders. Command posts (CPs) for combat units were unwieldy and were not optimal for supporting mobile operations. Communications and automation facilities were slow to deploy to the region and to redeploy when they arrived. Mobile subscriber equipment (MSE) was unable to keep pace with the maneuver units.¹ In addition, the range of the combat net radio (CNR) was insufficient to support mobile and deep operations at division and above. Moreover, various agencies controlled a large variety of databases and systems, which meant the databases and systems differed in communications media, software data and control standards, and protocols for data sharing and connectivity. As a result, the flow of data between sources and users was not

¹During ODS, MSE was fielded to only two divisions. The Tri-Service Tactical Communications system, which employs an architecture different from that of MSE and does not interoperate well with it, had to be adapted with interface equipment and software to be connected to MSE nodes.

streamlined or smooth. This meant that operators had to devote much of their time to configuring a modified architecture to achieve interoperability between systems, instead of being able to use an in-place architecture designed for interoperability to perform their operational missions. There was also no CPO at the same time, either within or across command levels. Reports required to promote better awareness of the current situation across all commands were lacking. There was often no accurate, timely, or uniform assessment of the friendly force status or locations of units. The Global Positioning System (GPS) was not integrated into the operating systems so that commanders could know where their units and key elements were situated at all times.

Many of the deficiencies identified above are procedural and operational rather than tactical. Thus, the greatest benefit to the Services' ability to conduct operations, especially joint operations, would derive from policy changes at both the operational and tactical levels.

Implied Needs from ODS Findings

Timely Reports for C² During Mobile Operations. A key finding was that situation awareness is critical to promoting C² agility, particularly in a mobile operation. The commander must stay abreast of the friendly-and-enemy situation to make the rapid, informed decisions necessary to maintain momentum, exploit opportunities, and prevent fratricide. This means that tactical CPs at brigade and battalion must continue to receive, process, and transmit timely information while they are moving, to provide a current picture of the operation at all times for all commanders and their staffs.²

Communications and automation must enable the commander to be kept informed of critical information and to be alerted to situations requiring quick decisions. Commanders need the most current perception of the operation, tailored by them to their problems or the decisions they are preparing to make, with an alerting override when they need to be confronted with new and unanticipated data they must deal with immediately, or when various inputs exceed a chosen threshold. The alerting function is what allows the commander to allocate his attention and to help avoid information overload in any particular category.

Smaller, More Mobile Command Posts. Another key ODS communications finding was that the current CP configuration of tactical, main, and rear was not optimal for supporting mobile operations. Corps, division, and brigade

²Hence, the Army's Battle Command Vehicle (BCV) concept.

commanders apparently need a small, mobile forward CP electronically linked to a larger, generally static rearward CP. The forward CP would focus primarily on the operation and synchronization of close and deep operations, while the rearward CP would perform detailed analysis, coordination, and planning, as well as conduct rear operations.

Given that it is feasible to link rearward and forward CPs electronically over a relatively long distance, in-theater operations could be supported from a relatively secure "split-base" structure in which the rear base could be located in or outside the continental United States (CONUS). Certain intelligence, logistics, personnel service support, and deployment or redeployment operations could be supported by a static, nondeployable headquarters.

Automated Reporting of Friendly Asset Location to Help Counter Fratricide.

GPS proved to be a tremendous C² asset during ODS, since it provided users with highly accurate unit location data. However, it did not automatically update commanders on their units' positions. While the units knew their own locations more accurately than ever before, the data still had to be reported manually, and there was no central location that automatically received, aggregated, and disseminated position updates to others (e.g., Air Force and Naval strike teams) who needed it. To be most useful for countering fratricide, position location of friendly forces and their assets must be automatically communicated and displayed at CP and fire control centers. These data would also be valuable to alert Air Force and Naval units of the precise locations of friendly ground units to aid in preventing fratricide.³

Range Extension for the CNR. Another of the ODS communications findings was that short-range CNR, while adequate to support brigades and battalions, requires range extension to meet division requirements. The best long-range CNR appears to be tactical satellite (TACSAT) or equivalent. However, a TACSAT system is currently not operable while moving, and future channel availability and responsiveness are problematic. High-frequency radios are not sufficiently reliable to support command communications. In addition, MSE provides unreliable or tenuous support to brigades during rapid and long-

³Subsequent to ODS, additional units of the Position Lightweight GPS Receiver, a handheld GPS receiver that enables accurate position location to be readily made available to its users, were procured, and approval was authorized to develop the GPS ABCS Tracking System to track individual mobile equipment for asset and resource monitoring, e.g., armored vehicles and other weapons. However, as yet, there is no system for automatically identifying and reporting the location of such equipment to control centers to help counter the fratricide problem experienced in ODS. However, the current Army initiative to digitize the battlefield is procuring applique hardware for a variety of battlefield equipment. The applique hardware is to include a communication device, a position locator, a computer processor, and a display and input device.

distance movement, because its nodes lack the necessary agility to provide consistent and robust support to forward units.

Relevant Findings from Previous RAND Work

As mentioned in the previous section, this study took advantage of experience and knowledge gained from a series of RAND studies, including studies of conflict scenarios and contingency operations, mobile operations, CP structure, communications, space-based systems, automation, image displays, sensors, quantifying and measuring system capabilities in operational outcome terms, and performing system trade-offs. The following reports were particularly useful:

- *Defining Commanders' Information Needs* (Kahan, Worley, and Stasz, 1989)
- *Support for the Army Intelligence, Electronic Warfare, and Target Acquisition Master Plan* (Cesar, 1988)
- *Recommended Strategy for the Army's Role in Space* (Harris, Horn, Cesar, and Steinberg, 1993)
- *Estimating the Army's Intelligence Requirements and Capabilities for 1997–2001: Analytic Support to the Military Intelligence Relook Task Force* (Bondanella et al., 1993)
- *A New Approach for Measuring the Operational Value of Intelligence for Military Operations* (Cesar et al., 1993).

The MI Relook Study was particularly relevant. It determined that, during ODS, the intelligence system connection architecture lacked responsiveness and that the MSE took a lot of time to deploy and could not keep pace with maneuver units when they were engaged in combat. The research also revealed that commanders prefer imagery to written messages and prefer information to be simultaneously broadcast to units participating in the same operation, rather than relayed serially through the chain of command.

In other studies, researchers learned that the heavy reliance on space communications during Operation Urgent Fury and ODS, which included leased commercial terminals and transponders, such as the International Telecommunications Satellite (INTELSAT), offered many advantages (e.g., wide area coverage, the ability to exchange imagery, and increased ground mobility)(Harris, Horn, Cesar, and Steinberg, 1993).

What the Future May Bring

In deriving C² operational objectives, we made some assumptions about the likely complexities of the future operating environment. For example, we assumed the following:

- There will often be rapid deployment to regions where units of hastily assembled task forces will converge and meet for the first time.
- Combat and noncombat operations will sometimes take place concurrently in the same region.
- Joint and combined elements will need to work closely together to synchronize training, deployments, and operations.
- Joint efforts will be complicated by differences in equipment, doctrine, software, standards, and procedures.

We also recognize the difficulties of ensuring that commanders are always connected to sources of information through all phases of deployment and campaigns. These difficulties, we assume, will be reduced as the Army alleviates its problems with the following:

- Maintaining uninterrupted systems and communications service while on the move
- Arranging handoffs to different agencies while en route
- Reducing the time and effort of setup, connection, tear-down, and safeguarding C² systems and communication equipment
- Providing continuous connectivity and data flows to the sustaining base and intermediate commands
- Minimizing the interfaces required for all connectivity (e.g., buffers, translators, specialized software) to achieve seamless interface and transparent, unburdensome, and continuous support to commanders.

Derived Operational Objectives

Many of the deficiencies identified above are operational rather than tactical. Thus, the greatest benefit to the Services' ability to conduct operations, especially joint operations, would derive from changes at both the operational and the tactical levels. Consequently, this study focused on the operational level.

From these findings and implied needs from ODS, findings from previous RAND research, and assumptions about the future operating environment, we postulated the following operational objectives for C²OTM:

- The ability to deploy forces rapidly to any region in the world, including CONUS and U.S. possessions
- Intraregional mobility equal to or greater than that of the forces
- Infrastructure for C² in place in the region ahead of or at least simultaneously with the arrival of operational forces and operating as soon as it is needed
- Reports about the environment, enemy locations and activities, and the location and status of friendly forces available to commanders and their staffs at all times
- Data needed to protect and sustain the force at all times regardless of mission, including noncombat operations
- Position location at the small-unit and vehicle levels, automatically collected, analyzed, and disseminated to and by one or more central locations to help guard against fratricide.

While we believe the Army will find merit in these postulated C² operational objectives, we believe the Army itself, in conjunction with the other Services, needs to describe its operational objectives by continually reexamining the informational data requirements of commanders for performing C² and by defining the anticipated movement dynamics of the forces in future operational settings. We believe the Army should specify and continually update and revise the required data, by type, and should identify the providers and intended recipients of databases and messages necessary for C², plus the desired message formats, content, volume, and timeliness expectations.

3. Deriving Information and Physical Requirements for the Operational Objectives

Given the operational objectives postulated in Section 2, we identified the following set of informational and physical needs that the components of any C⁴ architecture must satisfy.

Informational Needs

Fulfilling a commander's information needs is the primary basis for C⁴ system requirements.¹ Information reduces uncertainty in the decision space² of a recipient. Data are not necessarily information and neither data nor information are knowledge, although these terms are often interchanged. If the decision space is about the state of the sender, we have the basis for communication.

One difficulty in designing C⁴ systems to support commanders is that a commander who must acquire more knowledge about his or her decision space must rely on secondhand reports from a variety of sources over which he or she has no direct control. While those sources will genuinely try very hard to anticipate and respond to commanders' needs, any architecture that attempts to fully satisfy the informational requirements of all commanders in a given region with the same reports, whether or not they are broadcast, is bound to fail. Also, an architecture that does not ensure direct feedback between commanders and their sources of information, with guaranteed timely and relevant responses to their requests for data, will not be sufficiently adaptive.

Any C⁴ architecture, then, has at least four informational needs, which are summarized in the left half of Table 3.1. First, it must provide support for operations, consisting of data that are suitably timely for operations and that are accurate, sufficient, and understandable. Second, it must be fully interoperable with joint forces, combined forces, and civilian agencies, where necessary. Third,

¹For a discussion of this subject, see Cunningham and Taylor (1994) and Cunningham, Taylor, et al. (1993).

²*Decision space* refers to all subject matter that is related to a set of decisions for which a decisionmaker is partially or totally responsible and to the set of all possible decisions the decisionmaker may make.

it must provide comprehensive data, including all categories needed to support decisionmaking and operational planning. Fourth, it must be responsive to commanders' tasking and retasking to meet their changing needs.

Physical Needs

A C⁴ subarchitecture³ must also meet the six physical needs summarized on the right side of Table 3.1. First, it must be available when needed, so the relays and terminals and their connections must have the same deployment priority as the supported forces. Second, it must be self-sustaining (i.e., able to operate continuously in a region without infrastructure). Third, it must be as mobile within the region as the forces it supports. The terminals connected to the architecture must connect the users to their sources of data at all times and without the need to stop, set up, and make connections. Fourth, it must be adaptable, which means it must instantaneously, or very rapidly, accommodate all necessary changes (e.g., adapt to changes in the environment, add new users and purge unwanted ones, and conform to changes in plans, the conflict situation, and the mission). Fifth, it must be reliable and robust (i.e., it must have redundancy, be self-restoring, offer only minimum signatures, provide communications security, and be resistant to jamming). Sixth, it must provide support to, and be supported by, the CSS spectrum.

Finally, affordability is one of the most important attributes of an architecture, because cost is often the determining factor of the deployed capability.

Table 3.1
Informational and Physical Needs of C⁴ Subarchitectures

Informational Needs	Physical Needs
Supportive of operations	Available
Interoperable, joint and combined	Self-sustaining
Comprehensive data	Mobile
Responsive to commanders' needs	Adaptable
	Reliable and robust
	Supportable and supporting

³A distinction is made between the meta-architecture that includes all DoD system networks and the subordinate architectures referred to in this report, which are called C4 subarchitectures.

Ranges of Quantifiable Measures for Informational and Physical Needs

Although this study did not address in detail the process involved in actually measuring the informational and physical needs of C⁴ subarchitectures, it did consider a range of possible dimensions for them. The measures discussed below are not intended to be comprehensive, nor are they necessarily the best ones. Our goal was to describe an approach that might be further developed into a useful methodology for performing cost-benefit and trade-off analyses.

Ranges of Measures for Informational Needs

Although this study dealt primarily with qualitative criteria, it also considered that each criterion has an expected range with measurable dimensions. Measurable dimensions for "Supportive of operations" are timeliness, accuracy, and adequacy of data to enable planning and decisionmaking. Since only users can determine whether or not the data they received met their requirements, and only after the data were received, it is necessary to establish a range of accepted values beforehand. Consequently, the measures are the difference between the preestablished criteria for timeliness, accuracy, and sufficiency for each given situation. There is already Army-accepted precedent for this in the commander's situation briefings, his Prioritized Intelligence Requirements, and his Critical Information Requirements procedures.

Measures for "Interoperable, joint, and combined" depend on the degree to which equipment standards and operating protocols are interoperable, and the degree to which this is achieved can be measured in terms of the percentage of a force, unit, or system level that is equipped with interoperable equipment using suitable standards and operating protocols.

"Comprehensive data" refers to the understandability and usefulness of the data carried by the architecture and can be measured much like support of operations—the user establishes beforehand a range of accepted values, and the measures are given in percentages for the difference between the preestablished criteria (e.g., for each functional domain, if desired) and the results for each situation.

Although, in one way or another, all of the above categories help determine whether an architecture is "Responsive to commanders' needs," we refer here to his ability to use the architecture to task and retask sources of data to meet changing requirements. In this case, the measure is time, and the commander must preestablish the criteria for responsiveness.

Ranges of Measures for Physical Needs

Under physical needs, "Available" has a time dimension that ranges from having the C⁴ equipment arrive in the region either at the same time as the other early-entry systems do (e.g., mechanized infantry, fire support) to having it arrive at a later time (e.g., when the main forces arrive or just prior to the time they engage in combat).

"Deployability," which relates to availability in the region, can have several dimensions. Although this study does not deal with unit-specific deployability trade-offs, the Time Planned Force Development and Deployment List (TPFDDL) must be very sensitive to when C⁴ systems are deployed. For example, early-entry forces clearly need C⁴ systems that can be deployed with a minimum of airlift and sealift. However, it is not clear that separate C⁴ equipment used by heavy divisions needs the same degree of compactness as that used by lighter forces if the heavy ones have sufficient lift. If, on the one hand, heavy division equipment is to be deployed by sealift or can be prepositioned in specific theaters, size and weight limitations may not be as restrictive as they are for light or early-entry forces. If, on the other hand, both heavy and light forces depend mainly on airlift and have their C⁴ systems integrated in all major items of equipment so there is little additional requirement for lift, the time to deploy would be greatly minimized.

"Self-sustaining" also has measurable dimensions. For example, there are acceptable times when systems may be out of operation, including downtime planned to accommodate communication satellite or aerial platform orbits. Also, the number of platforms and systems required to maintain continuous, uninterrupted operations is another measure. This would include the number and types of alternate C⁴ systems required for backup.

How "Mobile" C⁴ systems can be quantified according to operational phases they are supporting (e.g., attack, counterattack, position or mobile defense), as well as by the echelon assignment. During ODS, the Army used tracked mobile C² vehicles (C²Vs), but they were unable to keep up with the faster maneuver units, not because the vehicles themselves were too slow, but because the time required to connect to the much slower-moving MSE grid was too long. Therefore, while the mobility requirement could be linked with the mobility rate of the maneuver units (e.g., presently, an average speed of 35 km per hour), the time it takes to maintain connectivity networks (i.e., the setting up and tearing down of antennas, the connecting of power units and other equipment, and the establishing of connections to the C⁴ subarchitecture and its meta-architecture) must also be considered.

Measuring how "Adaptable" a C⁴ system is involves both the time and data-volume dimensions. For example, a network of users (i.e., report recipients) and data sources will have a characteristic timeliness for each of the several missions it supports. The adaptability of a C⁴ system will also involve how fast a change can be accommodated, including changes in the user group, the data sources, or the mission assignment of all three components. Another adaptability measure is the volume of reports that must be generated for each combination of network factors.

"Reliable and robust" measures how well the C⁴ system can handle shocks, degradations, losses, and additions to the physical system. Examples of shocks to the physical system are losses due to enemy action or natural disasters. Reliability is often measured in two ways: (1) as the reliability of a design, and (2) as a resulting operational readiness rate. The latter can be influenced by the number of backup modes built into the design or the number of duplicate systems included in the TPFDDL.

"Supportable and supporting" can be measured in several ways. "Supportable," for example, describes whether or how well the C⁴ system can be supported by the armed forces in terms of manpower, training, organization, maintainability, resource requirements, etc., as part of the overall force. The supporting attribute measures how well the architecture supports the users in terms of timeliness of reports delivered, volume of reports, and overall responsiveness to data requests.

There are perhaps other categories and criteria for measuring them (e.g., maintaining continuity of operations with multigenerational systems as complete or major components of old systems are retired and new ones are fielded); however, we did not attempt to examine this aspect of the problem, because our focus in this concept-formulation study is on the overall compositions of architectures. The transition from today's C⁴ architecture to any new architecture will always result in a performance degradation from that predicted for the idealized new architecture, because the C⁴ architecture is so large that some elements are expected to be in transition, so the idealized architecture is never achieved. But this fact does not mitigate the importance of top-level comparisons of the characteristics of future C⁴ architectures nor the importance of understanding the transition issues.

4. Analysis of the Army's Current and Planned C⁴ Subarchitecture

In this section, we analyze the Army's current and planned C⁴ subarchitectures to determine how well they stack up against the informational and physical needs discussed in Section 3 and the operational objectives that underlie those needs. Following a brief discussion of a subarchitecture's basic components, the section examines the Army's current C⁴ subarchitecture, evaluates it against the informational and physical needs, and then discusses how the planned subarchitecture will address any shortcomings.

Basic Components of a C⁴ Subarchitecture

All C⁴ subarchitectures have three basic components: (1) information sources, such as databases, sensors that collect new data, and operational units that provide inputs based on their status and performance; (2) collection, production, and dissemination facilities (CPDFs),¹ which convert the raw data into usable products; and (3) users, such as commanders and their staffs, who give or receive tasking orders, store data, or transmit them to other operational forces. These components may be connected in various ways, and the connections themselves form an independent part of each subarchitecture. In this sense, we do not present complete architectures in this discussion, only their subsets. But how the subarchitectures are connected has an impact on how well they meet the informational and physical needs outlined in Section 3.

The Army's Current C⁴ Subarchitecture

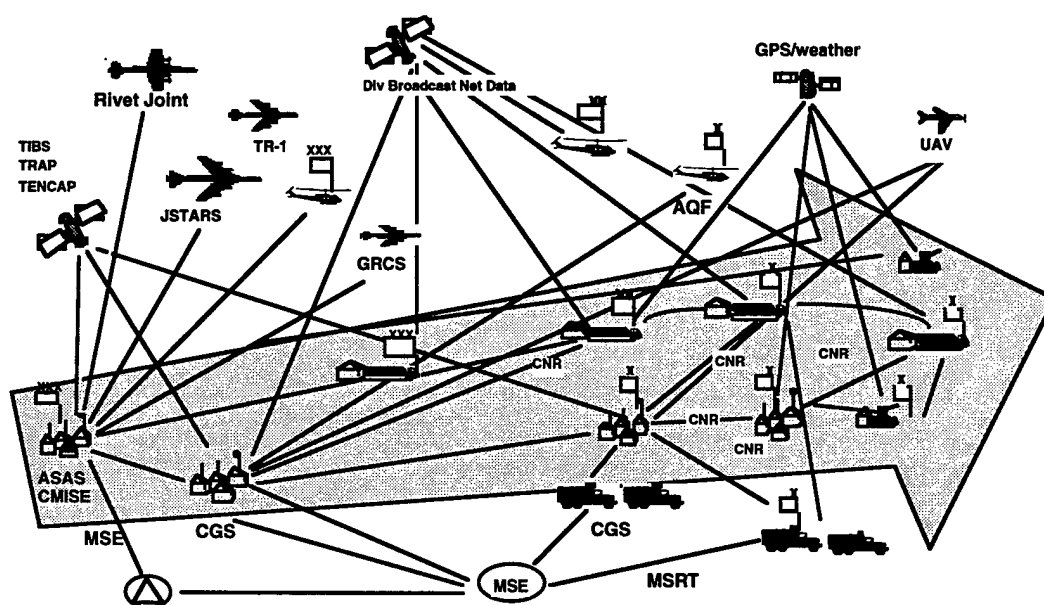
The Army's current C⁴ subarchitecture, which is illustrated in Figure 4.1, was based on the C² Mini-Functional Area Analysis Study and the MILSATCOM Architecture Study (U.S. Army Signal Center, 1993). This architecture is based on the philosophy that reports from all, or as many as possible, of the numerous inter- and intraregional systems should go directly to the commanders or their staffs. While the rationale for this philosophy is to ensure that commanders

¹CPDF is a term we coined to describe a central place where all source collection, production, and dissemination operations are performed and standard and special types of reports are prepared and disseminated.

receive timely and accurate data, the large and ever-increasing number of diverse systems is impractical to accommodate. They operate on different frequency bands and require unique terminals, which are continually changing, resulting in a CP that is large, cumbersome, operator-intensive, expensive, and easy to detect by an adversary.

Presently, there are several different types of data-collection and report-production facilities—some outside of an operational region (e.g., in the CONUS), and many set up within a region. Each is responsible for, and optimized to support, a particular functional domain (e.g., intelligence, maneuver, fire support, air defense, and CSS); thus, they differ considerably according to their subarchitecture designs, component systems, standards, and protocols.

Figure 4.2 provides a subset view of this architecture, showing its multiple subarchitectures, each of which feeds data on its particular topic to the tactical operations center (TOC) in a CP. Thus, there is one information production and dissemination facility for CSS, another for intelligence, another for maneuver, and yet another for other kinds of data to help promote situation awareness.



NOTE: The more detailed subarchitectures for aviation, MCS, TACFIRE, EPLRS, and many other lower-echelon systems are not represented in this figure. See abbreviations list for definitions of acronyms.

Figure 4.1—The Army's Current C⁴ Subarchitecture

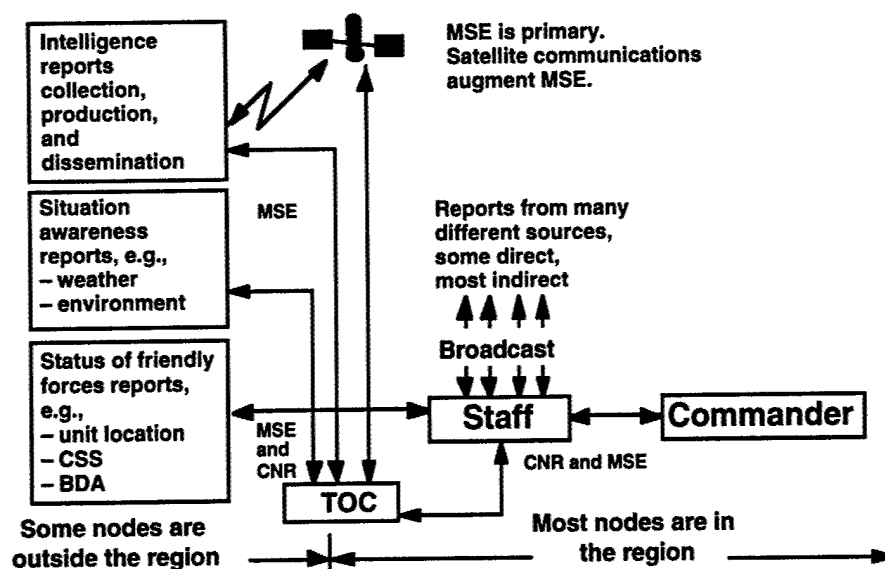


Figure 4.2—Schematic of the Army's C⁴ Subarchitecture Configuration

The feedback loops required to redirect collection planning and collection management efforts are organized according to specific functional domains (Combined Arms Control, 1992a). For example, in the intelligence production center model, these loops were designed for specific system operations (e.g., signal, image, and human intelligence; weather; and topography), as well as for position location and fire support. As a result, this architecture is difficult to control, and efforts to integrate operations (either horizontally or vertically) and to synchronize them may not be sufficiently timely or efficient.

The requirements for equipment and expertise to integrate and manage the large amounts of diverse data at a TOC and other CPs are massive, which increases the need for skilled operators there or further burdens the staff and limits unit mobility. The data integration process itself, notwithstanding the fact that new technologies can greatly speed up the process, detracts from the commander's ability to perform C².

The Army's Evolving C⁴ Subarchitecture

The Army is evolving its current architecture by integrating it with the Army Tactical Command and Control System and further with the Army Global Command and Control System. In this evolving architecture (shown in Figure 4.3), the CPs and the C²Vs receive data from a variety of CPDFs, each devoted to a particular function (e.g., CSS, intelligence, and other situation awareness reports), as well as from a number of sensors. The data products are sent to users

in the region primarily through terrestrial MSE links. The architecture would be augmented by satellite communication, and although there are plans for some reports to be broadcast to users and some space-based systems may be used for that, the plans call for doing so only for specific kinds of data along certain functional domain lines (e.g., warnings), rather than for all kinds of data.

Notwithstanding these incremental improvements, this subarchitecture is unwieldy and difficult to control, primarily because various kinds of data and formats from different data sources all converge at different times and at a single place for the commander to integrate and try to make sense of. This means that a C²V for the commander and his staff would probably require a multitude of different receivers and antennas to receive reports from all the different CPDFs and sensors. This requirement for a large number of transceivers to operate on many radio frequencies and for the associated antennas would adversely affect the CP's survivability and the C²Vs' mobility. In addition, this subarchitecture is still divided into physically separated processing centers set up according to, and optimized for, the functional domains (e.g., CSS, intelligence, fire support) and their sub-subarchitectures. Finally, deploying the large amounts of diversified equipment required at each CP would involve many operators and high costs. An alternative configuration that might overcome many of the built-in difficulties from functional domain rigidity would be to organize several more or less identical processing centers (such as CPDFs) that would produce and disseminate reports across all the functional domains or specified groups of them. Although they might be physically separated, they could be virtually centralized with data links.

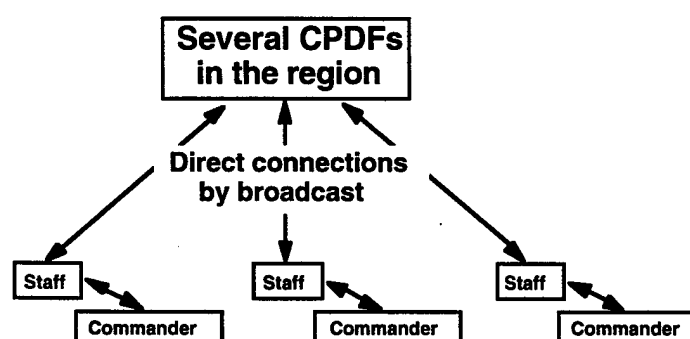


Figure 4.3—Army's Evolving C⁴ Subarchitecture

Evaluating the Army's Current and Evolving C⁴ Subarchitectures Against Informational and Physical Needs

Tables 4.1 and 4.2 present the apparent shortfalls in informational and physical needs of the Army's current and evolving C⁴ subarchitectures. The fact that these apparent shortfalls exist does not imply that this subarchitecture has no positive features.

In the following sections, we examine some elements of a C² architecture that can help it overcome the shortfalls described above: CtC communications, SIS, and CPO.

Table 4.1

Apparent Shortfalls in Informational Needs of Army's Current and Evolving Subarchitecture

Informational Needs	Apparent Shortfalls
Supportive of operations	Data lack timeliness, accuracy, and sufficiency for synchronizing operations
Interoperable	Limited connectivity with joint and combined forces or civilian agencies
Comprehensive	Connected to a large variety of data sources that use dissimilar reports, formats, and procedures; requires many skilled operators in the region
Responsive to commanders' needs	Mostly indirect connections to major sources of data; limited tasking authority

Table 4.2

Apparent Shortfalls in Physical Needs of Army's Current and Evolving Subarchitecture

Physical Needs	Apparent Shortfalls
Available	Must deploy large amounts of dissimilar equipment
Self-sustaining	Limited capability to operate without available ^a infrastructure in the region
Mobile	Requires setting up, tearing down, and moving a large variety of equipment to keep pace with mobile forces
Adaptable	Difficult to reconfigure systems to meet changes after systems and units are deployed
Reliable and robust	Large physical and electromagnetic signatures
Supportable and supporting	Large quantity of dissimilar equipment, which produces numerous line items and supply and training costs

^aBy available, we mean here that communications facilities for connecting Army systems are physically present in a region and that no political, commercial, or other restrictions limit their accessibility to U.S. forces.

5. Computer-to-Computer Communications

As revealed above, one major drawback to C² efficiency is that data transfers between computers currently take place over architectures that are not optimized for such transfers. In the past, except for Air Defense subarchitectures, all communications required the direct action of operators at both the sending and receiving ends. Now, many data exchanges are automated, taking place much faster than humans can assimilate or act upon. This section examines such CtC exchanges, looking first at when they should be used and then presenting some potential military applications for them.

Using CtC Exchanges

When CtC exchanges are used, they usually occur in situations structured to accommodate person-to-person (PtP) communications. One example that shows the inefficiency of this arrangement is Scud-busting. This process in ODS involved (1) employing sensors to search for, identify, locate, and acquire a transporter-erector-launcher; (2) transferring essential data to a weapon-control facility; and (3) observing whether or not the target was destroyed. All of these actions should have been accomplished within an extremely brief period of time. Without the appropriate architecture, data exchanges for such exceedingly time-limited operations will not be timely.

CtC should not use architectures designed for PtP for the following reasons:

1. PtP architectures are technically suboptimal for CtC uses. CtC networks are used mainly to exchange digital data to control machines, not to exchange imagery, voice, or text. However, all three formats can be sent as digital data.
2. Most CtC nodes have no reason to be situated at CPs if they are not directly involved in supporting human communications or monitoring the status of machines. Typically, these computers are integrated into other kinds of machines, such as sensors, automatic processors, and space and airborne platforms (including manned orbiting and unmanned aerial vehicles [UAVs]).

3. If operators intervene in the data streams of CtC architectures, they can delay or disrupt them. In addition, if CtC channels are available to people, they may, when communications networks are heavily loaded, decide to preempt those channels for PtP and computer-to-person uses. Such disruption of data flows can adversely affect the CP's operations or those of other commands.
4. Requiring CtC linkages to conform to PtP architectures that follow command hierarchical paths rather than those designed for efficient machine exchanges increases the number of nodes and data translation buffers required to achieve system interoperability. The best type of architecture for CtC is one that connects machine nodes directly. Machines can automatically exchange large volumes of data with other machines at much faster rates than humans can assimilate or act on.¹ Machines can also process the data, filtering and abstracting according to human instructions. Processed data can then be transferred to humans to make decisions or to set new threshold levels for desired actions.

Current and Evolving CtC Military Applications

CtC exchanges, especially digital data transactions, are definitely on the rise and are expected to increase.² Here are some current and evolving examples for military applications:

- On-board data processing
- Automated UAV operations
- Automated data relays and switches
- Integrated GPS receivers connected to control centers by line-of-sight (LOS) satellite relays
- Automated logistics tracking and inventorying
- Teleoperated mines and unattended data-linked ground sensors.

The Services should consider designing data network architectures for CtC and PtP uses that are independent of command hierarchies and not requiring CtC exchanges to conform to PtP command-level hierarchies (e.g., corps to division to

¹This means that standards and profiles to achieve system interoperability among machines are just as necessary for service interoperability among commands and their forces.

²As noted earlier, subsequent to this study, the Army initiated a major effort to digitize the battlefield. This effort is being managed by the Army Digitization Office (ADO) as part of the Force XXI activities. Three major exercises are included in the plan: a digitized Battalion Task Force XXI (94); a digitized Brigade Task Force XXI (97); and a digitized Division XXI (99). The digitization of the battlefield initiative is one of three thrusts the Army is pursuing to achieve Force XXI.

brigade to battalion). This will require characterizing and analyzing the expected volume and rates of CtC and PtP data exchanges for future scenarios to determine system hardware, software, interfaces, and other requirements.³ Then, analysis will be needed to determine the appropriate balance in the total C⁴ architecture between those resources that are devoted to reports exchanged via imagery, text, and voice and those that are devoted to digital data exchanges between computers and other machines.

CSS is one example that could greatly benefit from an optimized CtC architecture. Currently, CSS centers and units must compete with the maneuver elements to communicate. We suggest it would be better to use small space transponders installed in major items of equipment (e.g., tanks, armored personnel carriers, howitzers, missile launchers, air defense weapons, and aircraft). Transponders are especially appropriate for this purpose, and they can be connected to small space-based terminals by adapting evolving technologies for hand-held transceivers for personal communications for CtC exchanges. By embedding transponders in major items of equipment and connecting them to on-board sensors, CSS-relevant data about the status of equipment and consumption of key commodities (ammunition and petroleum, oil, and lubricants [POL]) could be automatically monitored and reported. Data from the transponders could be automatically sent to CPDFs via low-data-rate satellites (e.g., INMARSAT) in low and medium earth orbits. There the data would be aggregated, analyzed, and sent to operators at various command levels and to the sustaining base in the form of reports via a PtP architecture. These data could also be used to update CS and CSS databases and to inform various action centers and commands/agencies when thresholds—set by operator personnel and continually monitored and adjusted to conform to the operation's dynamics—are reached. This will prove very valuable to depots and ports concerned with planeloads and shiploads, to armies and corps concerned with major supply areas and shipping container loads, and to divisions and brigades

³Consider a typical scenario of a conflict situation in which, initially, combat forces are deployed in a region for a relatively brief time, followed by an extended posthostilities period during which U.S. force elements are engaged in security assistance, civil affairs, humanitarian assistance, medical support, and other similar noncombat, peacekeeping activities, occasioned by periodic unrest brought about by sporadic violent outbreaks of terrorism. The requirements for CSS data exchanges during the times of relative calm can easily dominate those needed for combat operations, both at the beginning of the campaign and during any sudden unexpected outbreaks of violence. However, if the architecture is designed primarily to support combat operations, with connections to specialized data sources, it could be too inflexible to rapidly shift to the new dynamic requirements, and its adaptation might be clumsy and possibly incur unacceptable delays. Consequently, the objective architecture should be designed to readily shift, all or in part, to support simultaneously either combat or noncombat operations or both by readily and seamlessly adding and deleting providers of data and new users. Designing the architecture in a very open way and from a top-down perspective would provide the greatest flexibility, thus enabling dramatic swings to be accommodated. For this reason, architectures that are based primarily on space-based capabilities that can instantly shift in any direction appear to offer major advantages over ground-based ones.

concerned with supply points down to truckloads. There are obviously commercial applications as well.

By conceptualizing and describing new applications for C²-related technologies that could have both commercial and military uses, the Army also has an opportunity to identify resources from industry and elsewhere outside the Army. In the past, the Services developed new technologies that were later transferred to commercial applications as spin-offs. We propose that in the future, the Services look ahead to where new technologies are going and identify ways both the Services and commercial entities can benefit from those technologies.

One example would be to develop mobile crisis control action centers for use by the National Guard, the Federal Emergency Management Agency, and the U.S. Department of Forestry for combating large fires, as well as for use by states and large cities where natural disasters and civil disorder may occur. This kind of equipment might also be useful to many countries for dealing with civil strife and supporting disaster-relief efforts.

Other specialized groups also depend on mobile C²Vs and accurate and timely reports for their operations when they are in remote areas. Three examples are environmental survey, oil exploration, and fire-fighting teams. The Army may wish to help promote the aims of specialized groups by collaborating with them and with industry, pooling concepts and designs, and sharing test data. The Army also stands to benefit from this kind of interaction with industry representatives by encouraging and gaining support from those groups that require advanced systems and specialized software, thus lowering production costs and enhancing designs for both military and nonmilitary applications.

Another idea would be to encourage the television industry to develop highly mobile C²Vs connected to an overhead relay and switch for reporting television and radio newscasts and other related communications from regions with limited or no available communications infrastructure. The television industry is already experimenting with a similar capability using ground-based communications augmented with commercial satellite links. One illustration of this is NASA's Advanced Communications Technology Satellite (ACTS) demonstration program.

ACTS is an experimental satellite platform being used for both commercial and military applications. The Army Space Command has already demonstrated its use in providing voice, high-data-rate video, and other data transmissions (including video conferencing between tactical units in the field) and in sending weather, intelligence, and other operational data. Experiments have been conducted with divisions at Ft. Hood, Texas, and Ft. Irwin, California—where

the NTC is located—that involve sending unit position location data and operational plans.

ACTS is also being used for financial data transactions between the Huntington Bank in Columbus, Ohio, and one of its check-processing centers in Parma, Ohio, to demonstrate its capability for providing a backup data link if landlines are interrupted.

Another particularly interesting ACTS experiment that has great potential for both military and commercial mobile ground and airborne applications is its demonstrated capability for placing telephone calls between a ground station and a commercial jet traveling at high speed. Electronically steered antenna beams on the ACTS satellite have been used to track the aircraft while in flight to keep it in constant communications with the ground station.

Yet another example is to consider what technologies and applications for them might follow handheld communications satellite transceivers, which are now being rapidly developed and made smaller and more capable. Although the number of people in the world who might wish to communicate via satellite telephony could eventually be on the order of one billion, the types and quantities of equipment many of us may want to keep track of could be much greater. Possible Army and commercial applications are for monitoring the location, status, and performance of equipment. This could be accomplished by installing small, low-cost transponders in major items of equipment. The transponders would be connected to a variety of on-board sensors and would periodically send their data via space-based terminals.

The trucking industry has already begun extensively using transponders to monitor and automatically report to central points the location of each vehicle in its fleet and such other events as speeding, the arrival or nonarrival of trucks at designated points, and load weights over specified limits. Presumably, the Army could also benefit from this technology, beyond just applications for CSS, by employing sensors and transponders in military vehicles and weapons, which would be queried periodically to send operational status and historical data to centers through space-based links. One way the Army might help promote this capability is to conduct limited and, therefore, low-cost feasibility demonstrations using transponders from commercial fleet equipment adapted to military applications. Some examples of operational data are unit locations in forward, rear, or flank areas to designate the "front line" trace, rate of advance, target areas being fired at, the number and types of rounds fired per weapon, firing rates by ammunition type, number and types of rounds on hand, and crew status.

Thus, business opportunities apparently exist in these and a number of other C²-related areas. The Services should not only be ready to capitalize on military applications but should also help bring about wider commercial ones. Finding new commercial applications should encourage industry to provide resources for development and offer lower production costs for military systems through large-scale production. We are not suggesting the Services invest heavily in developing new technologies; rather, we are suggesting they become actively involved in partnerships with other potential users in formulating concepts for both military and commercial applications and in helping guide developments so the results can be available to them at an affordable cost.

6. Switchboard in the Sky

Another C² deficiency is that the data commanders in a region need are often not available to them when desired. For example, if commanders' needs for data are responded to mainly after requests are received, synchronizing execution will be difficult, and communications capacity, which will always experience high demands during peak operational periods, may be overloaded when it is most needed. And since the architecture must be engineered for peak demands, the number of channels and their carrying capacity would have to be very large. Experience obtained from past campaigns indicates that the times when demands for information were high were often when communications availability was low (House Armed Services Committee, 1992).

This section explores a concept designed to remedy this deficiency that we call the "switchboard in the sky" (SIS). To do this, SIS proposes "pushing forward" anticipated data in advance of demands. In such a system, database changes are constantly trickling in and updating the commanders' databases; as a result, there should be fewer demands (mainly for additional data and elaboration), and satisfying those demands should be less hectic. In the remainder of this section, we discuss the concept in more detail, before turning to examine the components of such a concept (and their functions), the postulated performance of the concept against the above-mentioned informational and physical needs, and some considerations of the concept's cost and performance trade-offs.

The SIS Concept

We define the SIS as a decision-support mechanism designed to provide continuous connectivity between the sustaining base and the deploying and deployed units in a region. Given the focus on making all the data needed by commanders in a region available to them as they desire it, an overhead relay and switch (the SIS) would be a key feature; however, its importance lies in helping to make reports for planning, decisionmaking, and executing current operations continuously available. To provide this support, time-critical reports would be broadcast to all units by the overhead relay; the remainder would automatically update the local databases in the CPs' computer workstations with current situation data through optimized CtC data exchanges.

This “pushing forward” of anticipated data in advance of demands has important implications for both system architecture and communications channels. To help us visualize how data might be pushed forward, temporarily held, and kept up to date while users pulled the data they needed from it, we originally used a “data carousel” as our model. However, while this analogy was useful, we have since refined our thinking and now consider a “data salad bar” analogy to be a more accurate model. This is because a carousel implies standard-sized slots containing finite quantities organized according to predetermined data domains, whereas a salad bar implies an infinite variety of items to choose from across all the functional domains. At first, this distinction may seem unimportant; however, we believe it is an essential part of the conceptual process of creating and analyzing data architecture designs (e.g., in helping to understand how data should flow, where the memory nodes should be situated, and what their sizes should be).

For the SIS concept, we envision the memory residing principally in four locations:

- At the sustaining base, where large, complex historical and current databases for all the functional domains would be maintained and kept up to date
- At each of the CPDFs, where selected data are pulled from the sustaining base, and data are added from current collection sources and feeder reports from the deployed units
- At the computer workstations in the units, which are continually being updated by the CPDFs
- At the SIS platform for on-board operations, which would be monitored and directed by the CPDFs, for temporary “store and forward” exchanges between other space-based and terrestrial relays to ensure virtual connection continuity, and for temporarily storing messages from ground terminals (e.g., commanders’ requests for additional data or data bursts from embedded transponders).

This fundamentally new arrangement for memory storage would not follow the command hierarchy of field army, corps, divisions, brigades, and battalions. Instead, each of those commands would obtain the data it needs for its operations from one or more supporting CPDFs.

The SIS Architecture

Figure 6.1 illustrates the connection architecture conceptualized for the SIS. Its basic components are a single CPDF (although there might be several in a

region), an overhead relay and switch, one or more space-based relays, and the mobile C²Vs in the region, including both those of the TOCs and those of the commanders and their staffs.¹ The functions of each of these are described below.

The Collection, Production, and Dissemination Facility

The CPDFs would provide points for receiving and disseminating all database updates and other reports pertaining to regional activities, including those from the sustaining base and from units in the field. Its databases would be continuously updated with data received from sensor platforms, system or functional-area-specific processing centers, and other sources, such as friendly

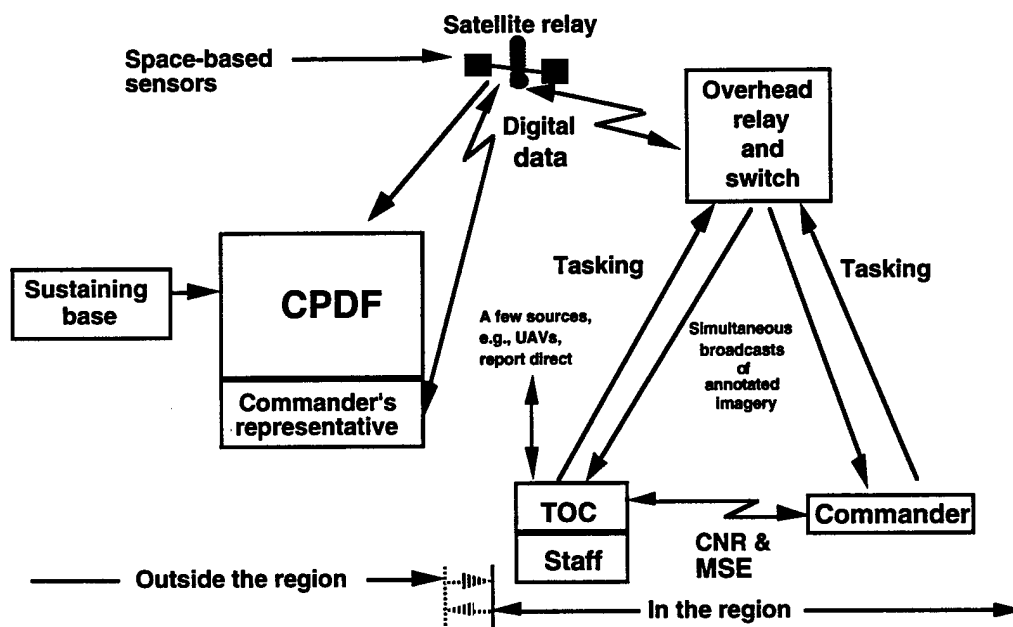


Figure 6.1—Schematic of the Switchboard in the Sky

¹Although military and commercial satellites positioned to cover regions where future conflicts and natural disasters might be expected are a solution over the long term, highly responsive “fly-away” packages employing other types of platforms (e.g., manned or unmanned aircraft with the same basic equipment for communications and data exchanges as on satellites) could provide essential coverage for unexpected contingencies in the short term in remote regions having little or no available communications infrastructure. For reasons of efficiency and economy, the ground terminals would need to work with both the actual or proxy satellite systems regardless of the type of platform. Obviously, such fly-away packages would have major implications for architecture designs, system interoperability, and joint and Service doctrines.

units and their databases. For example, reports automatically sent to the sustaining base and the theater of operations via the overhead relay, mostly by space-based relay, would include CSS data on such commodities as appropriately aggregated POL and ammunition consumption data, equipment and supply status, and the current accurate location (with the aid of GPS) of all friendly units. Reports received from sensor platforms (e.g., Joint Surveillance and Target Attack Radar System [JSTARS], Advanced Synthetic Aperture Radar System [ASARS], Guardrail Common Sensor, and the Ground-Based Common Sensor) would be disseminated to units in the region through the overhead relay in standard formats generated by the CPDFs. Reports received from space-based platforms would include weather and terrain imagery, reconnaissance, surveillance, and target acquisition data.

The CPDFs would process these data and then produce and send reports using standard formats to the sustaining base, the headquarters of interested commands in the region, and other centers through the SIS. These reports would probably include target identification, battle damage, and friendly force locations, as well as intelligence and Mission, Enemy, Troops Available, Terrain-Time (METT-T) reports. Standard formats might include graphics (e.g., photographs, maps, map overlays, mosaics, charts, graphs supplemented with tables), written messages, and voice messages (such as warning broadcasts). Because the MI Relook Study determined that commanders prefer to receive information in graphical format (Bondanella et al., 1993), reports would be provided principally as imagery with icons and notations, followed by amplification when requested by the recipients.

To minimize the need for additional tasking of collection resources and attendant delays in information retrieval, the CPDFs would constantly send updates of these reports to the SIS relay. Time-critical reports—such as warnings of incoming fires, target data, and alarms about impending fratricide—would be broadcast directly to those who need to act on the information immediately (perhaps temporarily preempting whatever channel they may be viewing at the moment). Other reports would automatically and continually update the databases in the units' computer workstations through optimized CtC data exchange architectures.

Note that the CPDFs would be equipped to interface with the dissimilar systems of the various sources of data (e.g., the different types of collection systems) and with the different categories of users (e.g., National Guard, coalition forces, and allied civilian agencies, such as police, fire, medical, and disaster relief teams.) This would eliminate the need for the CPs and combat units to be equipped with a variety of different radios and Communications Electronics Operating

Instructions, thus greatly promoting interoperability and limiting the need for specialized equipment. In addition, the simultaneous broadcast of reports in graphical formats using universally joint standard icons and military symbols would minimize the time involved in producing reports in various languages and dialects and would speed comprehension among users no matter what their languages.

The CPDFs would be located in several places, in the rear and forward areas of a region and in CONUS. They should be sufficiently distant from the conflict area so they would not be under constant threat and would not need to be moved throughout a campaign.

To minimize the need for long-haul, two-way communications and the burden on many bands and frequencies, we have envisioned the SIS as being located essentially at some intermediate point between the sustaining base and the region of operations. However, for some coastal and island regions, it might be physically situated some distance away and off-shore, as long as LOS contact with terrestrial terminals could be maintained.

The Overhead Relay and Switch

The overhead relay and switch would broadcast time-critical messages from the CPDFs using a single band of frequencies, regardless of the type of message, in the same manner that commercial television does. Unit location, aided by GPS, would be relayed by the SIS to the CPDFs and to appropriate data-analysis and weapon-control centers, vehicles, and patrols. The SIS relay would immediately broadcast time-critical messages aimed selectively at those in the region who must act on them, as well as send the messages to the appropriate CPDFs to be forwarded to other centers, if appropriate.

The SIS relay would be within LOS range of all terrestrial nodes in a region. Thus, given adequate coverage and network connectivity, it would eliminate the need for ground-based relays (and, thus, the vulnerability of the soldiers needed to install, operate, and maintain such relays). It would provide connections not only between the regional users, the sustaining base, and the CPDFs but also among the users themselves (i.e., it would extend the range of the combat net radio), facilitating communications among mobile CPs—vertically and horizontally—between all command levels, regardless of their physical separation. To provide multilevel security, the relay would use packet switching, channel or frequency hopping, and encryption.

While our schematic (Figure 6.1) shows the relay and switch as a single entity located over the region of operations, this is not the only possible configuration. The same function could be served by a single satellite or a small constellation of them, by one or more airborne platforms, or by a combination of space and airborne platforms. If restrictions prohibit overflying a region, orbits might be offshore or in a neighboring country. What is necessary is that unobstructed LOS paths are provided for communications and data exchanges from a variety of physically separated and functionally diverse data sources to other different sets of physically separated and functionally diverse data users. For experimentation, exercises, and staff and operator training purposes, this could even be accomplished by installing the SIS on one or more tethered aerostats or on tall towers (see Appendix B).

Ground Coverage as a Function of Platform Altitude. Whether an SIS relay is situated on the ground; a mountain; a tower; an aerial platform, such as an airplane or a tethered aerostat; or in a satellite, the area covered on the ground from a single point is proportional to the platform's altitude and LOS distance, which is derived by the following formula:

$$\text{LOS} \approx \sqrt{2RH} ,$$

where the value for R is $4/3$ earth radius and H is the altitude of the platform.

For example, at an altitude of 1 km, the LOS extends about 125 km; at 6.6 km it extends 322 km; and at 13.2 km it extends about 455 km. Thus, at an altitude of around 13 km, a platform would probably cover an area of operations for a corps. It can be seen from Figure 6.2 that, at an altitude of 6.6 km, a moderately large island nation could be entirely covered if the terrain permits LOS. At the higher altitude of 13.2 km, there is some chance to stand-off the observation platform from the island, but only if the island has a favorably configured geometry (as indicated in the example shown in Figure 6.2).

The number of platforms needed for larger operations can be determined by the linear area to be covered divided by the number of relays at a given altitude (Bondanella et al., 1993, pp. 113–119).

Space-Based Relays. Depending on the location of the CPDFs relative to the region of operations, one or more space-based relays may be required between the overhead relay and switch and each CPDF. Space-based relays are not necessarily on satellite platforms. They may be on a surrogate satellite, such as manned or unmanned fixed-wing aircraft, UAVs, and tethered aerostats.

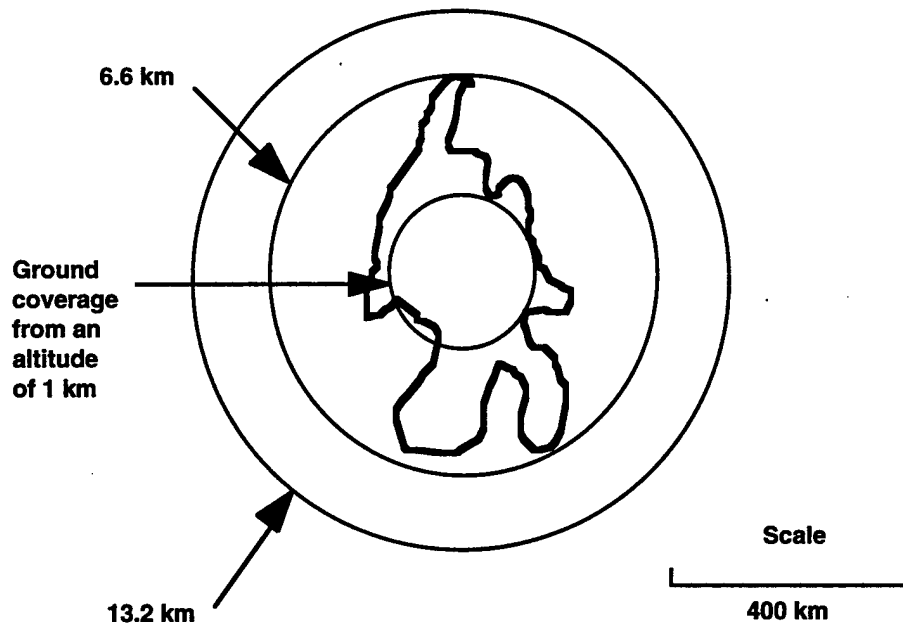


Figure 6.2—Ground Coverage of a Notional Island from a Relay on an Aerial Platform at Altitudes of 1, 6.6, and 13.2 km

Standard Report Formats. The use of standard formats for reports for broadcast to recipients in the region would have the advantage of conserving communications capacity by minimizing the number of two-way data exchanges. In addition to broadcasting the data available, appropriately tailored standardized data structures would conserve relay capacity on satellites (or other types of platforms), because only changed data would need to be sent, and the same data structure would be interoperable with multiple recipients, greatly reducing duplicative transmissions. In addition, less tasking of the CPDFs for updates would be necessary, because the standard data structures would automatically provide much of the needed data, so the reports can be tailored to suit individual users' changing needs.

Command and Control Vehicles

The SIS architecture would minimize the complexity of communications and data exchanges between computers in the region. Because the CPDF handles problems of connection within and between the Services as well as with the Services' and allies' dissimilar equipment, less computer equipment, less communications equipment, and fewer operator personnel in the region would be necessary. The C²Vs and the tactical operations centers would be equipped

with computer workstations, which, to receive all desired reports sent from the CPDF, would be tied to the channels broadcast from the SIS overhead relay. Based on each commander's needs and the conflict's dynamics, the operators at these CPs and their TOCs, under the commander's direction, would redirect the CPDF's efforts through appropriate retasking. The overhead relay would also provide the connections for this between the commander and other data recipients and the CPDF.

Analysis at the TOCs would be essentially limited to that using locally generated data combined with data provided by the CPDF and processed with respect to the local decision problem at hand. More general types of analysis would be performed at the CPDF and at remote centers that supply data to the CPDF, including the sustaining base. Tactical sensor feeds would be sent to the CPDF.

The commanders and their staffs could be equipped with two-panel computer notebook terminals that can be linked to the overhead relay and switch either directly or through the CNR. Two panels would be more convenient than just one, so that receiving messages and preparing new ones using the received data could be concurrent. Thus, commanders would receive standard reports from the CPDFs as they choose wherever they may be. Each commander would direct his staff about new decisions, orders, and priorities relative to the operational plan. The staff, in turn, would analyze and communicate any new collection and production requirements. A staff representative in the TOC would send those tasking requirements to his supporting CPDF through the overhead relay.

Postulated SIS Performance

When measured against the informational and physical needs set out earlier, the SIS concept appears to have a number of potential benefits.

Informational Needs

With regard to informational needs, the concept provides good support for operations in that it would ensure that reports meet the commander's needs and are responsive to his tasking. Also, the data provided would be timely, accurate, and sufficient. In addition, since it is designed for connectivity with joint and combined forces and civilian agencies, this concept would be easily interoperable. Production of comprehensive reports would be relatively easy, since the architecture would use multiple distributed CPDFs to provide operational data across all the functional domains. Tasking would be responsive, since the commander would be directly linked to the CPDF network.

Physical Needs

Since there would be less need for air- or seallift to move equipment and operators to a region, deployment would be fast; thus, the concept appears to meet the need for availability. The architecture would also be self-sustaining, since operations would not depend on existing infrastructure or requirements to install landlines in a region. Regional mobility would be handled through the use of overhead links for both inter- and intraregional data dissemination and tasking of databases and collection sources. In addition, networks could be reconfigured rapidly to meet changes, so the concept would be adaptable. Moreover, the SIS concept meets the need for reliability and robustness with minimum physical and electromagnetic signatures. Finally, it is easily supportable, since only a few different types of equipment would be deployed to the region.

Considerations for SIS Concept Cost and Performance Trade-Off Analysis

The impacts on costs, force deployability, force mobility, timeliness of reports, and other factors discussed earlier would have to be analyzed to determine whether the SIS concept could be better implemented using either spacecraft or aircraft, or a combination of the two.

In Table 6.1, to aid understanding of some of the key factors in a cost and performance trade-off analysis, we present a matrix of possible factors related to SIS performance and costs.

The table shows that the location of the SIS communications relay could be in geosynchronous orbit, medium earth orbit (MEO), low earth orbit (LEO), or on aircraft flying in the region. Also, the SIS could have its message switching system positioned at the same location as its communications relay system, or it could be located at one or more of the CPDFs described earlier. In addition, the SIS could have its message storage system positioned at the same location as the communications relay system, at one or more CPDFs, or this system could be located at both CPDFs and at the communications relay system.

Table 6.1
Key Factors Related to SIS Performance and Cost Trade-Offs

SIS Location	Message Switch Location	Message Storage Location	Estimated Performance ^a	Estimated Costs ^a
Geosynchronous orbit	With comm relay At CPDFs	At comm relay At CPDFs		
Medium earth orbit	At CPDFs With comm relay At CPDFs	At comm relay and CPDFs At comm relay At CPDFs		
Low earth orbit	At CPDFs With comm relay At CPDFs At CPDFs	At comm relay and CPDFs At comm relay At CPDFs At comm relay and CPDFs		

^aFor future analysis.

Considerations for SIS Location Options

The position of the communications relay will determine the size of the coverage area of a single SIS platform and system and the time constraints associated with this coverage. The coverage provided by a geosynchronous satellite in view of the area of responsibility (AOR) will be continuous and sufficiently broad to cover most AORs (except possibly at extreme southern or northern latitudes). One geosynchronous satellite communication relay may provide sufficient message relay capacity, especially if all its capacity were devoted to this mission.

However, if the SIS concept employed a LEO satellite instead (e.g., one in a 100-minute (760 km) circular orbit), the coverage provided would be intermittent and brief. Therefore, a number of satellites would be needed to provide continuous coverage of a relatively large AOR (e.g., one with an approximate area of 1,000 km²). The number of satellites required depends on orbital altitude and the acceptability of periodic interruptions (predictable) in communications. At an orbital altitude of 760 km, about 60 satellites would be required for continuous communication. At an orbital altitude of 1,250 km, communication over a 1,000-km link can be maintained about 70 percent of the time by a constellation of 12 satellites with a maximum outage of 12 minutes. About 30 satellites would be required for continuous coverage. If the orbital altitude is raised to 5,000 km, continuous coverage over a 1,000-km link can be maintained by a constellation of eight to nine satellites.

If the SIS switching function were deployed on aircraft, the instantaneous coverage a single aircraft would provide would be significantly less than that provided by a satellite, although for some AORs this could be adequate. Thus, a large number of aircraft may be needed to provide coverage for a large AOR, especially if continuous 24-hour coverage is needed.² In addition, a relatively large amount of airlift or sealift may be needed to deploy the number of SIS aircraft, crews, and support equipment needed for operations in a large AOR.

On the other hand, if a purely satellite-based SIS concept were considered, it would require much less airlift to deploy in a rapid deployment operation (only the SIS ground terminals—possibly in-theater CPDF systems—would have to be deployed to theater, instead of all the above and the SIS aircraft with all their support equipment). These lift concerns draw into question whether such a concept would satisfy the criteria we listed at the beginning of this section and point out the need for both detailed specification of the SIS concept and the operational environment.

Considerations for Message-Switching System Options

With regard to options of where to put the message-switching system (either at the CPDFs or on a satellite), it should be noted that it would be considerably more expensive to put such a system on board a satellite than on an aircraft or on the ground or a ship. A message-switching system is essentially a computer system that can identify, sort, and route messages. Putting such a computer system on a satellite is complicated and entails significant additional cost relative to a surface-based solution, since the computer chips must be radiation-resistant if placed in geosynchronous orbit or MEO. Until recently, this was not even possible; now, it is only possible with low-data-rate systems.

Considerations for Message-Storage System Options

Similarly, the cost and design implications of either putting a message-storage capability on the satellite or at the CPDFs are not presented here. Message storage on board a satellite implies needs for on-board message processing and for large amounts of solid-state memory or other magnetic-media memory devices. Space qualification of this additional hardware would be a significant additional expense. Because of the space and power limitations on most satellites, the amount of on-board memory storage will be limited relative to

²For example, the ratio between aircraft aloft and on the ground is typically 1:5 (as in the case, for example, of JSTARS and ASARS).

what would be available using ordinary computer servers located at the ground-based CPDFs. These design trade-offs need to be included in any analysis of SIS options. Alternatively, the message-storage system could be put at the CPDFs.

Other Considerations

The trade-offs defined by the three satellite system choices listed above are actually more complex than indicated when one considers the fact that antenna gain and satellite power requirements vary according to satellite altitude and the ground-terminal antenna size and power specified. Therefore, the range of system costs and capabilities for the SIS concepts could vary enormously.

These cost trade-offs and other implications of design differences are mentioned here simply to point to the need to flesh out the SIS concept with an appropriate level of specificity.

7. Common Picture of the Operation

As discussed in the previous section, one important feature of an effective C⁴ architecture is that it provide automatically disseminated reports based on tailored, standardized data structures, so that key data, which is relevant to formulating pending decisions, would be immediately available to the commanders and their staffs in the region. As we have stressed, commanders and their staffs, as well as providers of CS and CSS, need relevant, timely, and accurate data on the current status of operations to help them make decisions, plan and execute operations, and analyze and assess results. They also need the results of analysis to help them plan future operations beyond those currently being executed.

We have also stressed the need to present data in graphical formats with supplementary object identifications and explanations, both because (as previous RAND research indicates) commanders want such formats and because the facts about a given situation are generally easier to grasp (by both U.S. forces and allies) and apply from graphical formats than from written communications.

In this section, we discuss how data needed for a commander's awareness of his situation might be presented graphically to provide a CPO.¹ More specifically, the section first examines what a CPO is and what it does, how a CPO would be generated and disseminated, how a commander's information needs could be defined, and some of the benefits of a CPO.

Defining a CPO and Its Purpose

What It Is

What is envisioned by the CPO is a series of graphic images that could be viewed individually or in combination, much as a series of acetate overlays are placed on a map, to produce a composite illustration of particular facts related to a particular area and situation. Basic images that might be combined include the following:

¹Note that this does not mean the common picture will consist exclusively of images. The graphics will often be supported by icons, lines, arrows, and other symbols and text, as well as tables, graphs, and figures for detailed elaboration if the user wants them.

- Topography of a commander's AOR
- Major terrain features (e.g., lakes, rivers, mountains, swamps, desert areas)
- Likely avenues of approach (e.g., roads and road networks, choke points, defiles, major obstacles, barriers, mines)
- Dispositions of friendly forces
- Dispositions of neutrals (e.g., civilians, hostages, noncombatant individuals and elements)
- Dispositions of opposing forces
- Weather forecasts and expected weather effects on friendly and opposing force mobility and other capabilities
- Areas affected by storms, earthquakes, floods, fires, contamination, etc.

For example, the background might be a map of preferred scale, and the details and icons overlaid on it might include relational objects, such as avenues of approach, road networks, mountains, and lakes; point objects, such as friendly and hostile units; area objects, such as obstacles and obscurants; and graphic objects, such as sensor imagery products, including motion pictures and still pictures on video clips. Additional details accessible from the CPO might include tables, graphs, photographs, or written text to provide more detail about such things as personnel status, availability and locations of consumables, and logistic support. The capability of magnifying or reducing the map's scale would also be included to enable commanders to focus on details within a particular area or to view the larger picture.

What It Does

A CPO would provide commanders with comprehensive and timely views of the current operational situation, and of past, current, or future operational plans. While the same data would be available to all levels of command, one important feature would be to allow users at each command level to easily access only the amount of detail desired (along the lines of the data salad bar analogy referred to in the previous section). Thus, the user would be able to select the area, scale, and particular details relevant to his needs. A commander would, for example, be able to access what he wants to know about friendly and opposing forces in his particular area or the entire region of operations, as well as what he wants to know about elements on his flanks, in the rear of his position, or deep in his opponent's rear area.

This means that commanders need a principal information agent with whom they can execute battle commands in the same manner they interact with maneuver subordinates who serve as their agents in their own functional domains. Just as he interacts with his other commander and staff subordinates, a commander would give instructions to his principal data manager and information agent in terms of the decisions he intends to make and his informational needs to support them. His agent would ensure his commander's intent is understood and that the commander understands his information agent's plan to carry out the intent, down one more echelon in that process.

Two terms can help us understand the CPO concept. The first term is the common data set (CDS); the second term—the common graphical data set (CGDS), which is the iconic representation of the CDS—is a subset of the first term. Iconic representation fits ideas into a specified language of limited vocabulary. The limitation of vocabulary is what helps make for commonness, but only at coarse resolution.

Two individuals at different echelons could look at their own situation at different levels of resolution in terms of the CDS or CGDS. So long as the available data set remains common, they could choose to adjust their displays to be the same. Their perceptions and understanding are necessarily different, but they have a common reference from which to work. However, and necessarily, some local event will occur that runs contrary to the CDS. At that moment, the local commander's view will instantly cease to be "common" until the CDS is updated to incorporate this new reality. This raises the question of who will update the CDS, and on what basis. It also raises the issue that the CDS is never precisely accurate—that it must always be slightly out of date.

Generating and Disseminating the CPO

The CPO would be produced at a CPDF using data from its own databases, those of the sustaining base, and those of other agencies. The standard and special reports it prepares would be primarily in the form of imagery, with textual, tabular, and graphical backup as described above. Anticipating the informational needs of commanders and staffs in the region, each CPDF would then push relevant reports forward through the SIS, which would broadcast the reports, enabling the commanders and staffs in the region to access them as desired. The images and their textual and graphical backup would be regularly updated by the CPDF, and the local memory storage of the computer workstations would be constantly updated by trickling updates to them around

the clock. Constant automatic updating of local databases, by itself, is an important concept.

Software at the regional workstations would be used by operators to manipulate the imagery received from the CPDF to produce refined CPOs pertinent to each commander's needs. Note that the framework of the CPO is common to all the commands, but the data are pertinent to each commander's decision or action informational needs. Operators in the regional commands would be needed primarily to ensure the relevance of each CPO report according to the commander's wishes and to task the CPDF for additional reports or amplifying data, as necessary. Note also that the subarchitecture for the computer networks would not necessarily follow the hierarchical lines of force organization but would be tailored for maximum efficiency to support CtC connections. The very fact that the computer architecture need not mirror the command architecture allows freedom to experiment with different architecture forms to optimize them.

All hardware and software would be standardized across the region of operations. In addition, the hardware, software, standards, protocols, and display formats would, to the extent practical, be the same for all situation report categories, including those for intelligence, topography, weather effects, CS, and CSS (e.g., engineer, maneuver control, fire support and communications). This standardization should reduce to an essential few the unique skills and operations to be performed at the CPDFs (e.g., photo analysis, weather effects on trafficability, and intelligence operations). Since the intelligence community has already developed highly refined doctrines, procedures, and facilities for gathering, producing, and disseminating intelligence, its reports might be considered as prototypes for other kinds of reports. However, it is important to avoid the rigid stovepipe approach of any particular functional domain, because such domains have inherent biases, specialized databases, and hierarchical report distribution. The key is to design the architecture to support decisionmakers first and then to ensure that the subarchitectures of the battlefield operating systems are compatible, not the other way around.

Defining Commanders' Information Needs

In conceptualizing the CPO, we drew on interviews with former commanders and previous RAND work to determine what kinds of data might be needed (Kahan, Worley, and Stasz, 1989). This work provides a foundation on which the CPDF's standard reports can be based and on which a prototype CPO could be constructed. However, designing and optimizing the standard data format

structure and reports for the CPO would require testing and analyzing commanders' actual requests and usage.

This could be accomplished using prototype CPOs and recording the computer operations a commander performs to modify them to meet his needs, since the patterns with which he selects certain graphical images and amplifying data and the amount of detail he typically asks for will reflect his decisionmaking patterns. Analysts can then use sensitivity analysis to determine what kinds of data are most needed across a range of typical combat and noncombat scenarios for various kinds of decisions (e.g., planning, attacking, defending, and assisting with disaster relief). This method of recording and analyzing commanders' (or staff members') computer operations ("mouse tracks") to determine the kinds of information they desire and its information structures has important implications for all the Doctrine, Training, Organization, Leader Development, Materiel Development and Soldiers elements, especially for doctrine and training.

This knowledge can be used to further develop and optimize the CPO standard data structure (including the types of icons, symbols, maps, and resolution ranges), the CDS and the CGDS, as well as the desired report formats the CPDFs should be designed to prepare for sending to regions. Since the types of reports and the amount of desired detail will always depend on the situation and will vary with the command level, type of unit, and commander, provisions could be incorporated in a network's architecture to evaluate the process and optimize it. These provisions would be at the CPDFs and CPs during exercises at first and, if practical, during actual operations in the field, especially when the tempo of conflict changes.²

Not only is it important to determine what kinds of data commanders use, it is also desirable to evaluate the usefulness of the information they derive from it for decisionmaking and planning. Analysts could assess how useful particular kinds of data are by, for example, examining it with respect to a set of criteria. One set of criteria for evaluating the utility of data to support operations might be the following:

- Relevance to the command level and subordinate units (e.g., to the current operational plan or a future one)

²During actual operations, these data would require protection, since they bear witness to the commander's decision process.

- Responsiveness (i.e., to what degree the data are suitably timely for executing operations based on trials employing various cycle times between a commander's request for data and when they are actually provided)³
- Accuracy (e.g., for planning, for attacks with weapons, or for assessing results of weapons employment)
- Adequacy to support the operation (e.g., sufficiency and balance of METT-T data)
- Availability, which depends on timeliness (i.e., capability to obtain additional data, as needed, governed by adequate control of the sources to preclude either data overload or unnecessarily rigid restrictions on the flow of data).

In addition, analysts can determine what effects on operations result from either providing a lot of certain kinds of data or, in test cases, denying or limiting it. Thus, it should be possible to measure the essential connection between the data provided and their relevance to decisionmaking and planning, which, after all, are the best criteria for measuring the value of information. Theoretically, at least, it should be possible to relate gaming simulations that use an interactive decisionmaking model—plus analysis of results, the relevance, timeliness, accuracy, adequacy, and availability of data to support operations—directly to campaigns and battles won or lost, lives saved, and soldiers at risk, including those operating unprotected terrestrial communications relays.

Another way to measure the data effectiveness a CPDF using CPOs provides might be to compare the amount of time a commander needs to make a decision depending on how (first separately, then in various combinations) relevant, timely, accurate, and complete the data received are. RAND has developed a methodology for quantifying and measuring the temporal value of intelligence data (Cesar et al., 1994).

Benefits of a CPO

The CPO would greatly enhance interoperability, since graphical displays can transcend organizational and linguistic barriers. Specifically, the ability of commanders to share data with all the other elements of their own units, as well as with other units involved in joint and combined operations (assuming the

³For experimenting with data availability to users according to variable predetermined time cycles, a tethered aerostat used as a satellite proxy platform at the NTC might be designed to fade in and out in a pattern similar to that of an actual LEO or MEO constellation, according to designated times patterned after the actual satellites' access periodicity.

same data standards and interoperability profiles are used by all the Services), would facilitate planning, maneuvering, targeting, battle damage assessment, and other activities. For example, higher-level commanders would be able to quickly designate their intent and objectives, from which would flow the selection of targets to attack, including the enemy's information sources. The selection of targets would be according to a designated order and a desired combination of the air, land, and naval weapons of subordinate units, for attacking targets with any combination of weapons of either a single or more than one Service, either simultaneously or sequentially. Furthermore, target data could be rapidly, and in some cases even automatically, sanitized, declassified, and templated to permit rapid dissemination to allies. In addition, the objects depicted in the CPO might also portray safe routes for medical evacuation or supply movements for noncombat operations, such as disaster relief, or the location of mines and the capability of hostile forces to conduct combat operations.

8. Conclusions and Recommendations

Conclusions

The main conclusion of this concept-formulation study is that it is feasible for joint task force elements to operate while moving by adopting new techniques for assessing information requirements and new technologies, architectures, procedures, systems, and, particularly, space-based systems. This requires major revisions to the current architectures that connect data sources with data users in a region of operations. Major improvements can be achieved by designing architectures with nodes that gather, store, arrange, analyze and disseminate data according to commanders' informational needs. Doing this involves, first, defining and then pushing forward the data that are most often needed in a region; second, employing standardized data format structures for reports; and third, providing each commander with the means to receive what he wants, when he wants it, and in the formats suited to his particular style of decisionmaking. In addition, the efficiency of those architectures can be greatly enhanced by optimizing CtC data exchanges separately from PtP communications.

Developing such architectures will require meeting at least two challenges, one doctrinal and one technological. Currently, there are separate doctrines for intelligence, fire support, CSS, and other functional domains, both within and across each of the Services, and current processing is centered on the source and domain, rather than on the decision. Although mandated by the Joint Chiefs of Staff (JCS), data integration is not yet based on a top-down design but on combining designs for established functions after each Service has first met its own perceived requirements independently. To achieve joint interoperability, the doctrinal changes necessary for cross-service and cross-functional exchanges must be focused on decisionmakers and must flow downward from a joint operations perspective before interoperability within one Service and across the others is considered.

Clearly, C² must dominate and set the stage for all the other functional domains based on some such perspective, so that all functions work together as an optimized whole. All the components of the C² architecture will flow from such a perspective: platforms and vehicles, frequency bands, terminal types and

quantities, equipment types, control systems, network software, standards, and procedures.

Many of the technologies needed to support the recommended doctrine are available. Key among these are the new system concepts and the development of data exchange architectures that apply to the technologies for displays, networking infrastructure, processing, system and subsystem control, user interface, and dissemination. In particular, the use of automated CtC data exchanges (aided by installing small transponders connected to on-board sensors in major items of equipment) and the presentation of C²-relevant data as graphical imagery are now becoming available and promise to enhance operational efficiency greatly. However, these new technologies will not mesh well with the mixture of systems and equipment and data system connection architectures currently in use and under development.

One reason for the current variety of C⁴ equipment and software is that different systems are designed at different times, using different technologies. Attempts to make systems technically compatible and interoperable are made subsequently through interface equipment buffers and software adaptations, but this approach only adds more disjunctures and contributes negatively to seamlessness.

Recommendations

Given these conclusions, we propose that the Army, in conjunction with the other Services and DoD agencies, first redesign the C² structure to be more responsive to operational commanders. The redesign should focus on meeting the commanders' informational needs and do so before examining the architectures and their systems, equipment, software, and interoperability standards to support those needs. The second task will be to design and evaluate a completely new open architecture (hardware and software) that is top down (as directed by the JCS [JCS, 1992]) and based primarily on C². In addition, rather than optimizing communication systems and automation subarchitectures for each functional domain first and then integrating them into a meta-architecture for C², all the other functional domains (e.g., intelligence, maneuver, CSS, fire support, air defense, aviation) should be an integral part of the architecture by design, beginning at the most fundamental data-element level.

As mentioned above, attempts to make systems technically compatible and interoperable are now being made through interface equipment buffers and software adaptations, which contributes negatively to seamlessness. Therefore, we recommend that a coherent architecture and standards for systems (now

being directed by the Defense Information Systems Agency) for interoperability be based top down from a joint operations perspective and that it be implemented over a period of several years in an evolutionary and programmed manner while obsolescent and noncontributing architectures, standards, and systems are disposed of aggressively.¹ The Digitization Master Plan being prepared by ADO should make joint interoperability paramount, including the doctrinal changes necessary for cross-service and cross-functional exchanges to support the joint operations perspective.

To develop such a coherent architecture, we recommend that the Army start by describing its operational objectives, preferably in combination with the other Services. This will require reexamining the data requirements of commanders for performing C² and decisionmaking and defining the anticipated movement dynamics of the forces in future operational settings.

It is important to emphasize the importance of defining informational needs first, before examining the physical needs of architectures, their systems' equipment, and software. The requirements for exchanging data and other informational reports must be fully analyzed before a C²V can be designed and its terminal systems identified or any subarchitecture can be adequately described. And because requirements are continually changing, the process for defining them must also be dynamic. The Army will need to specify the required data by type for both communications and data exchanges, identify the providers and intended recipients (both human and computer) of databases and reports necessary for C², and define the data structure and desired reports with regard to format, content, volume, and timeliness. This approach runs contrary to the Army's past approach; because of this, the systems the Army inherited and must now use make it difficult for the Army to follow the new JCS guidance (JCS, 1992).²

Defining C² subarchitectures by putting information before equipment requires addressing who makes what kinds of decisions at what levels and who must make decisions locally. Again, this approach is quite different from the

¹In analyzing the potential utility of all systems currently in use and under development, the Army should take the following approach to determine their suitability. If an item does not contribute substantially or if it contains obsolete equipment and software whose wearout period cannot be justified, new production should be quickly terminated and current equipment should be discarded as soon as possible while continuing to work to acquire the new objective architecture.

²Recently, Secretary of Defense William Perry directed the Services to define their legacy and objective C² systems; however, until the Army develops a comprehensive objective architecture for the future, it will be exceedingly difficult to identify which systems to discard and which to retain and upgrade. As a first step, then, an improved methodology for making trade-off analyses and a procedure for identifying and acquiring information technology in discrete steps are considered essential. (As an input to this process, Appendix A describes a concept for acquiring new technology in time-discrete steps.)

traditional one the Army uses, which involves periodically attempting to define all the communications requirements at a given time based on "who needs to talk to whom, how much and how often." Such an approach is typically inflated to cover all possible situations and can never be completed, because the environment and the Army are dynamic, and because the possible situations and, especially, the supporting technologies keep changing. This only further emphasizes the importance of focusing on decisionmaking as the principal objective and on defining the products needed for that before addressing the architectures and component systems.

The next step will be to develop a set of criteria that an architecture must satisfy to meet the desired informational and physical objectives. Then, architectures will need to be designed and evaluated against both criteria and objectives.

The architectures will need to be tested and improved. We recommend using the ADO as the office to conduct experiments as part of the Army's campaign plan for Force XXI. Experiments could be done in coordination with the Battle Laboratories to obtain, for example, clearer definitions of the SIS, CPO, CDS, CGDS, and the CPDF. The design of and responsibilities for maintaining databases and the content of CtC data exchanges (both forward and rearward), CS and CSS data aggregation, and reporting of CSS consumption rates should also evolve. Also, the automatic reporting of CS and CSS data through the new C⁴ architecture from units in the region through the overhead relay, to the CPDFs, and finally to the sustaining base should be developed, tested, and evaluated. In addition, the development and improvement of prototype CPOs, including the CDS and CGDS referred to earlier, should be tested to better understand the kinds of data commanders and their staffs require for decisionmaking and planning for both combat and noncombat operations and how reports can be structured and tailored to the particular preference patterns of commanders for decisionmaking, command and control, and planning future operations.

Finally, we recommend that the Army look for potential sources of resources from industry and elsewhere by conceptualizing and describing new applications for information-related technologies that also have potential military uses. The following are three example categories:

1. Mobile crisis control action centers for use by the National Guard, Federal Emergency Management Agency, the U.S. Department of Forestry, states, and large cities
2. Small, low-cost transponders connected to space-based data terminals installed in major items of equipment, along with on-board sensors, to

monitor automatically and to report periodically on status, location, on-board activities, and consumption rates (e.g., for a number of military applications, the operational condition of vehicles and weapons and the status of POL, munitions, and spare parts)

3. Highly mobile C²Vs connected to an overhead relay and switch for television and other news media reporting, environmental survey and oil exploration teams, etc., in regions that have limited or no available communications infrastructure.

Appendix

A. Concept for Acquiring New Information Technologies in Discrete Steps

Finding ways to select, develop or adapt, and integrate new equipment, software, and procedures into the current C⁴ architecture presents challenges, primarily because new data-collection, transfer, manipulation, and dissemination technologies are proceeding at a much faster pace than the Army or the other Services are presently capable of acquiring or assimilating. This fact, exacerbated by declining budgets for acquiring new equipment, could mean that adding new capabilities for improving C⁴ may be continually stretched out over a longer period. This appendix describes a concept for acquiring new information technologies in discrete steps.

The General Pace of Advances

Figure A.1 illustrates in a general way the pace of advances in relevant communications and automation technologies compared with the Services' ability to acquire and apply them in the future. As budgets become flatter and even turn downward, the gap between what technology can provide and what the Army can acquire will theoretically widen if a traditional sequential acquisition process is used.

Planning by Epochs

One way to address this difficulty might be to plan according to epochs—that is, points in time characterized by distinctive new ways of acquiring technologies for C⁴—and to design the systems in each epoch with the same generation of technology.¹ Thus, equipment, software, and operating procedure compatibility could be more readily achieved, instead of grafting new systems onto obsolescent architectures by patchwork, with the assumption that the epoch approach is both operationally desirable and cost-effective.

¹Epoch technology-acquisition models might be developed for systems of the other functional domains as well.

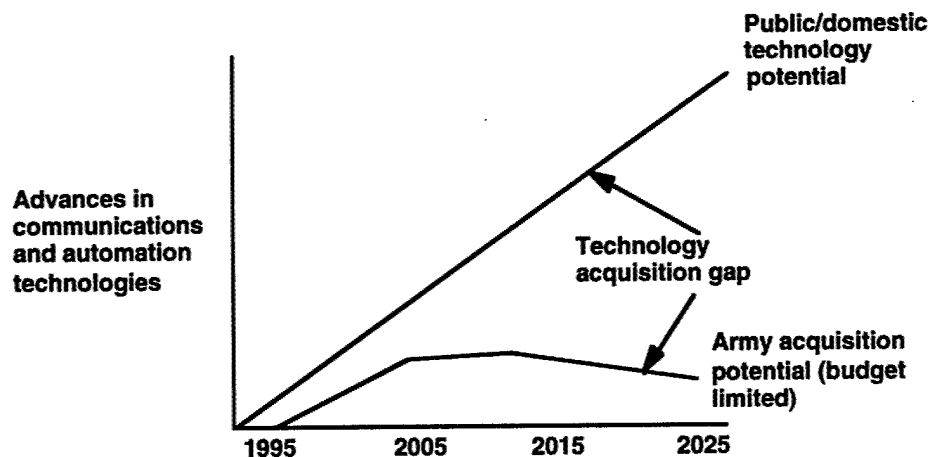


Figure A.1—Postulated Acquisition Gap Between Technology and Capabilities, Linear Acquisition Model

According to this concept, at any given time, there might be three epochs: the current step, an evolving one, and a future design. Each epoch would be characterized by significant changes in the major C⁴ elements (e.g., data processing requirements, network configurations, interface standards and protocols, and operating systems and their platforms). Within each epoch, the major systems and their components would either be the same or very similar to all the others in the same epoch; at least, they would be of the same technology generation and, therefore, should be highly compatible. Figure A.2 illustrates this concept notionally.

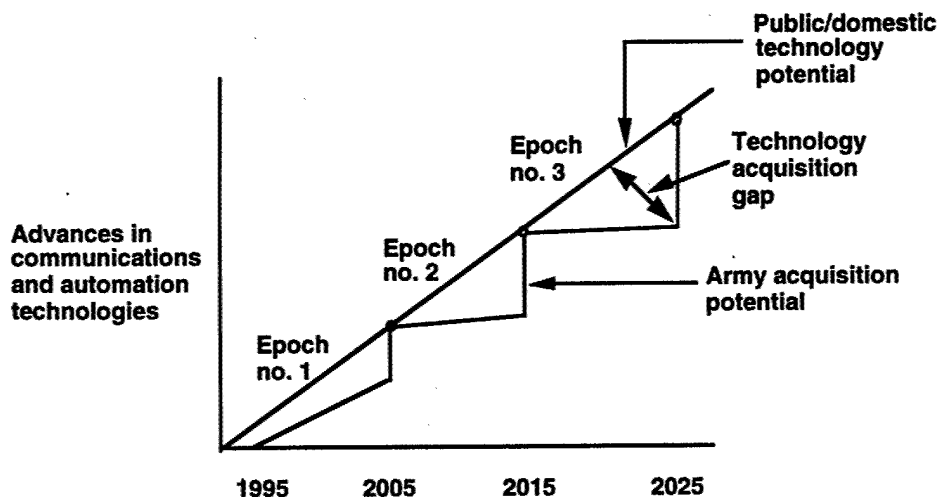


Figure A.2—Postulated Gap Between Technology and Capabilities Acquisition, Epoch Acquisition Model

B. Concept for Space-Based Platform Proxies for Battalion-Level Training at the National Training Center

This appendix briefly sketches a concept for creating a realistic environment for training by simulating a range of space-based platform options so units can interact with them through various space-based terrestrial components. Some of the objectives are to

- help warfighters train as they would fight
- give tactical units actual space-support terminals
- train regularly with space-based platform proxies (e.g., tethered aerostats, UAVs)
- experience ground coverage of space-based capabilities
- provide "hands-on" experience with actual equipment
- enable doctrine to be used realistically
- expose Army tactical decisionmakers to current doctrine for space exploitation, to interactions with space capability providers, and to other space mission-area organizations
- expose Army tactical leaders to materiel acquisition, software, standards for interoperability, protocols, and other key issues
- provide examples of the kinds of space-related training experience envisioned by the Army's leadership
- provide hands-on training with satellites at reduced costs
- provide operational and other data for performing cost trade-offs between space proxies and commercially leased communications satellites.

The area size of the operational environment where training is held at the NTC is represented by a central corridor that is roughly 15 by 30 km. This area is surrounded by mountainous terrain and is cut by a set of relatively low-lying mountains containing three main passes: Debnam, Brown, and Goat Trail. This area on the ground can be covered by a single aerostat operating at an altitude of about 200 ft, but there is a region of several km that is denied line-of-sight observation because of the low-lying mountains (perhaps around 1,000 ft high).

The situation is indicated in Figure B.1. A sensor platform at height H km is located at the end of the 15 x 30 km range and is R km from mountains M m high. An area X km long behind the mountains is obscured and is calculated by solving for X assuming a flat earth:

$$\frac{H}{M} = \frac{R+X}{X} ;$$

$$X = M \cdot \frac{R}{H-M} .$$

If $M = 1$ km and $R = 10$ km, then solve for X with H varying from 1.33 to 30 km above ground level.

The percentage of coverage of the 30-km long area observed by a sensor at height H then is

$$\text{Percentage coverage achieved} = \frac{1-X}{30} \cdot 100 .$$

Table B.1 shows the increase in percentage of the central corridor that is covered as the height of the sensor platform (H) is increased. Shown also is the associated decrease in the obscured region (X). These results are graphed in Figure B.2. Note the significant increase in coverage as the platform altitude is raised from 1.3 to 5 km. Although almost all the region beyond the mountain is obscured when the sensor platform is at 1.34 km, over 90 percent is covered with platform heights above 5 km and almost all when above 20 km.¹

The LOS is not significantly different at these higher altitudes than it would be for a space-based sensor. Thus, a tethered aerostat could be substituted for a

¹For lower mountain ranges, say 0.5 km, the high-percentage coverage values are obtained with sensor platforms at even lower altitudes.

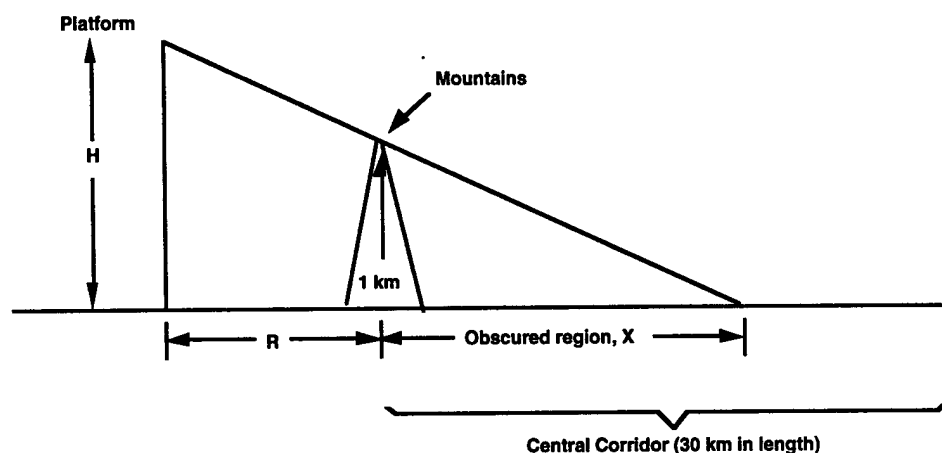


Figure B.1—Obscuration of the Lower Region of the Central Corridor

satellite during training exercises at NTC while providing similar coverage and connectivity capabilities using the same ground terminals, but at a much lower cost.

Some of the issues would be the obstacle an aerostat and its tether would present to helicopters and low-flying aircraft and the cost of providing and operating such a satellite surrogate.

Table B.1
Coverage of the NTC Central Corridor as a
Function of Sensor Altitude

Sensor Height (km)	Obscured Region (km)	Coverage of Central Corridor (%)
1.34	29.40	1.96
2.50	6.70	77.80
5.00	2.50	91.70
10.00	1.10	96.30
20.00	0.50	98.30
30.00	0.30	98.90

NOTE: Assumes the sensor platform is 10 km behind a 1-km-high mountain range.

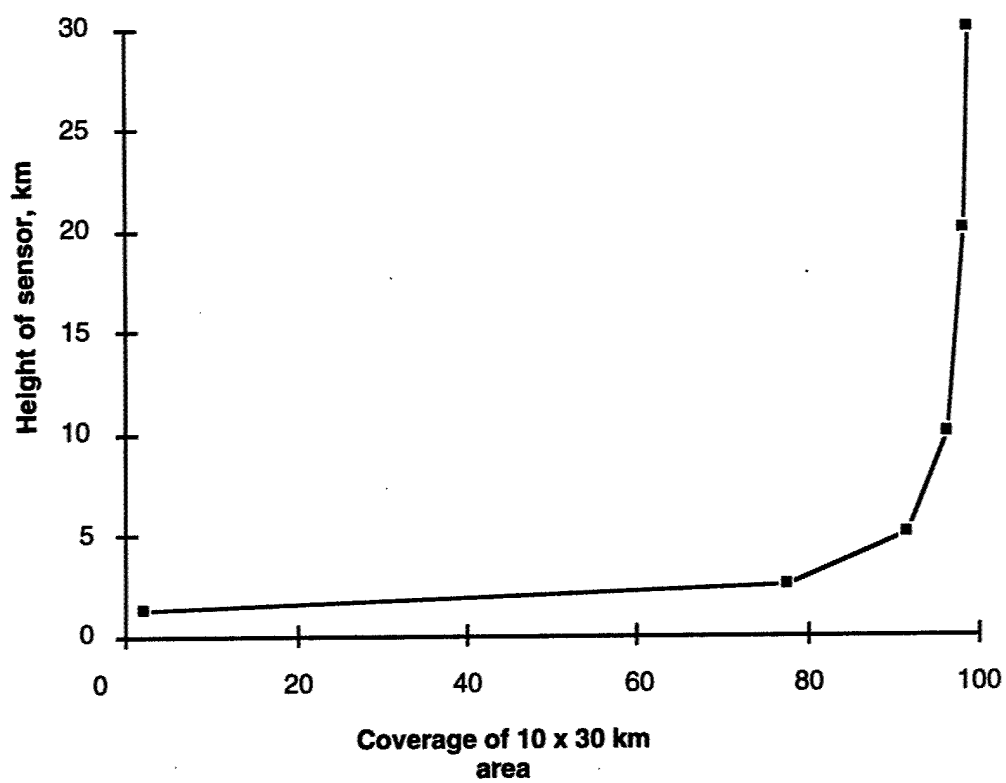


Figure B.2—Range of Sensor Coverage by Height

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